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Edited by
R. H. RASTALL and O. M. B. BULMAN

assisted by

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PROFESSOR W. G. FEARNSIDES
PROFESSOR LEONARD HAWKES
PROFESSOR O. T. JONES
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GEOLOGICAL MAGAZINE

VOL. LXXXVI. No. 5. SEPTEMBER–OCTOBER, 1949

The Yorkshire Dogger

IV. ROSEDALE AND FARNDALE

By R. H. RASTALL and J. E. HEMINGWAY

(PLATES XIII–XV)

(*Continued from page 225*)

PETROGRAPHY

Yeovilian

Serpula Sandstone

In parts of Rosedale and Farndale the Serpula Beds are exactly as in Fryup and Danby ; they consist of very fine-grained sandstones or silts, blue, grey, green, yellow, or brown in colour, according to the degree of oxidation, and always full of worm tubes. In many specimens it is clear that practically the whole of the material has been passed through the bodies of worms, leading to a very confused structure. The worm tubes may be several inches long : they are only occasionally vertical or straight, but usually arranged in an irregular manner. Fossils, usually broken and badly preserved, are sporadic, but determinable ammonites of the *striatulum* and *dispansum* zones have been recorded in different parts of the area (Macmillan, 1932, and this paper).

Yeovilian Ironstone, West Gill, Northdale

This was collected from 10 feet below the top of the Serpula Beds and is an example of the developing ferruginous rocks in the highest Yeovilian. It is a dark grey, heavy, fine-grained rock with much mica and many worm tubes, many rather indistinct ooliths and large pebbles up to 1 inch of black, phosphatized, oolitic ironstone. In general terms this is an oolitic siderite-mudstone, but the ratio of ooliths to matrix is very variable, some patches being almost pure siderite. The most notable feature is the distortion of the ooliths, which range from perfect spheres to long streaks in parallel position, giving almost a schistose appearance to the slice. The ooliths show strongly marked concentric structure which can also be traced in the distorted forms. The matrix consists of the usual minute rhombs of siderite, averaging 0·02 mm. long, with conspicuous dark cores : these are set in interstitial kaolinite which is only faintly visible unless stained with basic dyes.

While the foregoing must be regarded as an extreme case, nevertheless in many other places parts of the Yeovilian Series show some approximation to this type, on both sides of Rosedale. Detailed descriptions of these minor variants are hardly necessary.

Chamosite-oolite from Rosedale East Mine (Plates XIII A and XV B)

Specimens from the outcrop show this to be a dense dark grey ironstone with irregularly distributed chamosite ooliths. In the hand specimen it is closely similar to the Middle Lias ironstones of the Eston region, 12 miles to the north. Fossils occur irregularly and are usually preserved as casts or moulds. The micro-structure shows well-formed ooliths, often round in cross-section with good concentric structure and no distortion. The chamosite is of a very pale yellow-green colour and low birefringence. The nuclei where seen are either quartz grains or radial fragments of earlier chamosite ooliths. All the ooliths are slightly corroded and often partially sideritized with well-formed siderite rhombs penetrating their surfaces.

The siderite matrix is clearly of more than one generation. Dominantly it is dark brown and made up mainly of dark cores. Less commonly occurring is a paler, more coarsely crystallized siderite, secondary to the darker variety and sometimes replacing ooliths.

Of the inorganic detrital material quartz and micro-quartzite grains, ill-graded and corroded, are dominant, with only very rare mica and phosphatized grains. Among the organic debris echinoderm fragments are common, usually partly sideritized and chamositized. Many limonite-lined cavities are shell moulds. Altogether organic debris probably calcitic originally made up about 8 per cent of the rock.

Micrometric calculations of the mineral constitution of this ironstone, using a Dollar Micrometer gave the following results :—

	%
Siderite	64·8
Chamosite	25·4
Inorganic detritals	1·7
Organic debris	1·3
Space (mainly moulds of macro-fossils)	6·6
	99·8

Such a rock would yield 39 per cent metallic iron, which is appreciably more than the usually quoted figure of 32·7 per cent (Fox-Strangways, etc., 1885). Clearly, where sampled at outcrop the rock is richer, presumably more sideritic, than within the mine. This is confirmed by an examination of loose blocks collected near the adits, which were used because of lack of access to the mined area.

One such specimen is microscopically a very fine-grained oolite with few larger elements except a line of large pebbles on one side of the

specimen which is evidently from the top of the ironstone and was probably rejected for that reason. In a slice the rock is very simple, consisting entirely of a close aggregate of small ooliths, with very little matrix. There is no sand and very rare shell chips. The ooliths consist of fresh greenish-yellow chamosite with the usual concentric structure. All are round or oval and not in the least distorted, though a few are broken.

A second loose block is very different, as it contains a large proportion of calcite shells, parts of it being almost shell beds. Ooliths are not very numerous and are irregularly scattered. There is a good deal of mica and a few small pebbles throughout. The microscopic structure is very variable : in parts a fairly normal chamosite-oolite, with siderite matrix ; other patches are very calcareous and shelly and still others nearly pure siderite. This rock is distinguished from all others in Rosedale by the presence of true calcite ooliths with concentric structure. There are few detrital grains except rare pebbles of sandstone with a phosphatized cement, but many shells, shell-chips, and spines, all calcite, with one exception to be described later.

The ooliths are spherical or oval, the majority being pale green fresh chamosite with birefringence exceptionally strong for this mineral, but many are calcite ; some of these may be rolled pebbles of limestone, though their regular shape is against this, while others show concentric structure : in places several neighbouring but separated ooliths extinguish together indicating recrystallization. The matrix is fairly coarse brown siderite with dark cores.

One unusual feature is a complete gastropod of which the shell is now lined with sharp rhombohedra of brown siderite, while the body cavity is filled with a single crystal of calcite which also replaces the shell (see Plate XVB).

Chamositic Rocks from the Hollins Basin.

The lithologies of the Yeovilian at the Magnetite Mines are unusual, as are the field relations.

The green mudstone, which totals nearly 30 feet and which is the lowest bed exposed here, proves microscopically to be heavily weathered and limonitized. It consists of scattered grains of angular quartz silt (maximum diameter 0·1 mm.) with muscovite flakes up to 0·16 mm. set in a matrix which was originally a chamosite mud, but is now weathered. The outstanding feature of this rock is the manner in which small masses of sediment, usually oval in cross-section and up to 3 mm. in length are aggregated in a snowball-like manner in which the mica flakes are orientated circumferentially. Usually the constituent minerals of such aggregates are rather coarser and siltier in grade than the remainder of the rock and this, together with the

mica orientation, causes them to stand out microscopically. The arrangement of the micas also in some fields shows small sigmoidal curves. Clearly, these structures are developed after deposition but before lithification was complete. The pattern of the mica flakes would not support worm action, which results in random flake orientation, but suggests that this structure is micro-slumping, analogous to snowball slumping on a small scale (Fairbridge, 1946).

The overlying Yeovilian oolite (p. 215) shows microscopically abundant ooliths up to 0·6 mm. diameter of warm golden green chamosite slightly limonitized but with good concentric structure. Detrital nuclei are rare. About 25 per cent of the ooliths are well formed. The remainder are distorted to varying degrees, from simple irregularities which simulate unwrapping of the ooliths, through a series of linked forms which culminate in serpentine spastoliths derived from six or more united ooliths (Plate XIV A).

The matrix of the oolite is similar to that of the mudstone, a micaceous and silty chamosite rock, though this is more definitely sideritized. Again, the striking micro-slumping is present, emphasized by the concentrically arranged mica flakes (Plate XIV B). Such snowball aggregates are not confined to the mudstone matrix : at times the mica flakes are orientated around the ooliths, further supporting the view that these latter structures moved after deposition.

The overlying pebble bed in a pasty mudstone matrix shows the process of spastolithization carried to an extreme degree. The ooliths are smeared out into bands giving a schistose appearance and are welded together by a very small amount of interstitial chamosite. Quartz grains are not scattered as is usual, but aggregated into irregular wedges and lenses of quartz sand, very unlike a distribution resulting from normal undisturbed sedimentation. Pebbles up to an inch in length are numerous and well-rounded. They are usually silty and micaceous oolitic ironstones or micaceous grits, but in all cases the matrix is phosphatized to a brown, isotropic collophanite. It is noteworthy that the chamosite ooliths in the altered ironstones are quite undistorted.

From the foregoing it is clear that much of this unusual Yeovilian succession shows evidence of movement during diagenesis. Although these rocks were collected from the flanks of the magnetite-oolite deposits, probably only a few feet from their original extent, it is unlikely that the micro-slumping and spastolithization have any genetic connection with them. It is more probable that such structures arise here by slumping in the generally accepted sense of that term and by a less well-defined settling and sliding towards the middle of the developing and contemporary syncline. It is not suggested that spastoliths were at any stage soft (Pettijohn, 1949, p. 77).

Chamosite-oolite from Sheriff's Pit, Rosedale (Plate 1 B)

Although the evidence for the Yeovilian age of the ironstone is unproved (p. 212), its description is included here because both field evidence and petrographic characters support that conclusion. The rock is macroscopically conspicuously oolitic and in the slice is seen to be composed entirely of close-packed chamosite ooliths up to 0·5 mm. diameter in a matrix of siderite : there is no sand. The only other constituents are a few flakes of twisted white mica and a very occasional phosphatized grain. The ooliths are composed of pale yellowish-green chamosite, very fresh, with concentric structure well developed. Although birefringence is very weak, they give distinct black crosses. Broken ooliths are common and spastolithic distortion is developed. The siderite matrix is coarsely crystalline and colourless when fresh, but the edge of every crystal is oxidized to brown ferric hydrate. Some of the ooliths are extensively sideritized.

The heavy mineral concentrate is remarkable, as it consists almost entirely of dark blue anatase, obviously authigenic, with a mere trace of zircon and rutile. This assemblage has not been seen so strikingly developed elsewhere, though there is an approach to it in Baysdale.

The Ajalon Facies

This facies, which has a wide extension in Rosedale and occurs in Farndale (Blakey Mines), includes a considerable variety of rock types from coarse pebble beds to sandstones of fairly fine grain, variably ferruginous and often oolitic. It is not possible to give detailed descriptions of all these numerous varieties, and a few only of the more striking types will be selected, including especially those which can be matched elsewhere.

West Gill, Northdale

For the most part this is a rather fine-grained blue-grey rock, with distinct current bedding and occasional patches of broken shells and of fine-grained siderite. The proportion of ooliths varies somewhat, being rather higher in some patches of slightly coarser grain. Slices show approximately equal quantities of sand and ooliths in a matrix of siderite. Some ooliths are up to 0·6 mm. diameter and very perfect in shape, but there is every gradation from this to mere lumps and flakes of varying sizes. All consist of perfectly fresh pale green chamosite with fairly high birefringence and very well marked concentric structure. The sand grains are conspicuously angular and well graded, with an average diameter of 0·25 mm. The siderite matrix is rather coarse, with individual crystals up to 0·15 mm. diameter : they are usually cored and slightly oxidized.

There is a close resemblance to a rock from Baysdale, except for the absence of phosphate, probably dahllite, and to rocks exposed in the adits near High Hollins. These rocks, though more oolitic, are also obviously related to the khaki Woodhead Scar facies of Great Fryup (Rastall and Hemingway, 1943, p. 218).

Rosedale Abbey Bank

Macroscopically this is a slightly pebbly oolitic sandstone, dark blue-grey in colour, with many white specks and pale blue ooliths. The many small pebbles are mainly blue-grey mudstone. The matrix is dark grey when fresh and weathers brown.

In the slice small pebbles and sand grains are very abundant. The sand grains are angular to subangular, nearly all quartz, microquartzite

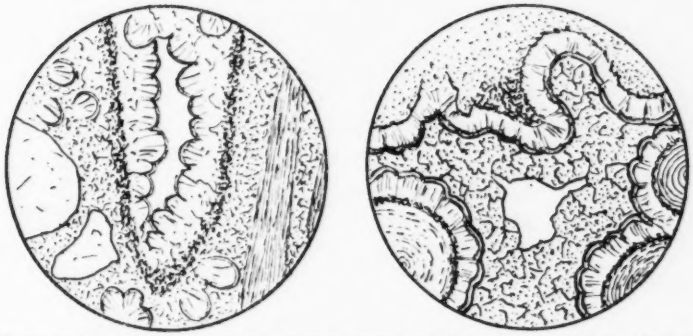
TEXT-FIG. 7.—Speckled oolite of the Ajalon facies, Rosedale Abbey Bank × 45. Chamosite ooliths with detrital quartz, cemented by siderite.

and feldspar being rare. The pebbles are nearly all isotropic, and are phosphatized with replacing collophanite. There is a number of shell and wood fragments. The detrital fragments and mineral grains are not only ill-graded but are irregularly distributed, suggesting fairly rapid deposition. Ooliths are numerous, round or oval, with very sharp margins and not distorted. They consist of pale brown chamosite, very fresh, and with good concentric structure. They vary much in size but rarely exceed 0·45 mm. diameter. There are some broken and irregular fragments of earlier ooliths (Text-fig. 7).

The matrix is entirely different from any other yet seen. It consists partly of siderite so finely crystallized that it gives only aggregate polarization and partly of a mineral which is probably new. This mineral occurs partly as small flakes and groups of flakes disseminated in the siderite and partly as a kind of corona structure, which is best appreciated by reference to the figure (Text-fig. 8). Its general appearance is distinctly chloritic, always with marked fan or

radial structure; colour orange-yellow, with feeble pleochroism; birefringence extremely weak, with negative elongation. The refractive index is almost the same as that of chamosite. There can be no doubt that it is a chlorite, and except for the colour there is considerable resemblance to Hallimond's thuringite (?) in the magnetite-oolite (Hallimond, 1925, p. 25). This mineral does not absorb methylene blue but is slightly stained by safranin, with some pleochroism.

There is considerable textural variation between adjacent parts of this rock in the field. Coarser variants, which are fairly coarse sandstones with pebbles up to 4 mm. in diameter, include numerous chips of pale green cement-stone, and in some layers abundant broken shells and wood fragments. Such rocks, blue-grey when fresh and weathering yellow, show microscopically a moderate number of ooliths, but the greater part of the rock consists of coarse sand in a



TEXT-FIG. 8.—Chloritic corona in part round ooliths. Ajalon facies, Rosedale Abbey Bank.

matrix of siderite. This is evidently the same as Ajalon rocks at Sandsend, Kettleness, Beck Hole, and Yew Grain, in Great Fryup Head (Rastall and Hemingway, 1940, 1941, 1943), as well as at Blakey Mines.

The microstructure of a fine-grained band is an aggregate of angular sand grains and a few rounded phosphatized grains, with a fairly large but variable proportion of pale green, ill-formed ooliths, ranging into irregular flakes of chamosite, with a matrix of oxidized siderite. Although the macroscopic appearance is different the microscopic character of the finer layers is very similar to that of the Woodhead Scar facies of Great Fryup and strongly supports our association of that facies with the Ajalon facies (Rastall and Hemingway, 1943).

The heavy mineral concentrate shows nothing very distinctive, but the large maximum grade size, poor grading, and the abundance of anatase and brookite, together with a few large brown tourmalines confirm its Ajalon association.

Near Rosedale Abbey Bank the Ajalon facies culminates in typical Black Oolite (p. 215). This rock is very simple in composition (Rastall and Hemingway, 1939) and here consists almost entirely of ooliths in a siderite matrix with very little sand. The ooliths, which are never distorted, but always spherical or ellipsoidal, usually consist of an outer zone slightly stained brown with marked concentric structure, and usually high birefringence (Text-fig. 9). The inner zone is a brown chamosite, probably slightly weathered chamosite of an older generation. The rock is a fairly high grade ironstone with low silica and somewhat calcareous, but unfortunately is of only limited development.

The Hollins Basin

The Dogger, near Kitching's deposit, is a typical example of the coarser varieties of the Ajalon facies. Macroscopically it is a coarse-grained gritty rock, fairly well bedded with visible wood fragments, a variable proportion of pale blue ooliths and small pebbles in a red weathering matrix. The microstructure is very variable, the chief constituents being sand, chamosite, wood, and shell fragments in a siderite matrix. The abundant sand grains vary much in size and shape and include a good deal of perthitic felspar. The chamosite is partly in the form of well-formed ooliths, but owing to distortion it shows every gradation to shapeless patches, nearly all of which, however, still show some degree of concentric structure. The colour is pale green and the birefringence extremely weak. The matrix consists of rhombs up to 0·06 mm. in diameter, now considerably oxidized, and they also replace parts of the ooliths. This same sandy oolite may be traced to the most southerly extent of the Dogger in Rosedale (p. 216) without lithological change.

The heavy mineral concentrates are large and red, characterized by great abundance of brookite in several habits. Anatase, in sharp pyramids, is rather scarce, and some specimens show a little pink garnet and red sphalerite. The two last named minerals are very characteristic of the Ajalon facies of the western area of north-east Yorkshire. No magnetite was detected.

This rock is too siliceous for a workable ironstone, though apparently attempts have been made to mine it. It is similar lithologically to rocks previously described from Kettleness, Beckhole, and Fryup (Rastall and Hemingway, 1940, 1941, 1943).

Blakey Mines, Farndale

This attempt to work the Ajalon facies for ironstone was foredoomed to failure, for although the section shows a remarkably fine development of these rocks, they are too siliceous and phosphatic to be of economic value. Black Oolite, similar to Rosedale Abbey Bank is developed here, but the greater part is closely related lithologically

to rocks of Ajalon facies in Great Fryup and south-east Rosedale, though with some special features of their own. The texture of much of the rock is coarse, almost a fine conglomerate in places. Most specimens contain a fair number of ooliths, difficult to see macroscopically except when separated by solution of the matrix in acid, when they are jet black (i.e. typical Black Oolite facies).

The micro-structure is complicated and hard to describe shortly. The chief constituents are sand, pebbles, and ooliths, shell chips being rare (Text-fig. 10). The pebbles are fine sandstones and chamosite-ooliths with the matrix replaced by brown collophanite. An unusual feature is occasional small pebbles of phosphate rock with dahllite in flat plates. These are pebbles of mudstone replaced by collophanite which has recrystallized to dahllite. Sand grains are dominant, varying much in size and up to 2 mm. in length : the larger are moderately

TEXT-FIG. 9.—Black Oolite, Rosedale Abbey Bank. × 45. Stained ooliths in a siderite cement.

TEXT-FIG. 10.—Black Oolite, Blakey Mines, Farndale. Stained ooliths and phosphate pebbles in a coarsely crystalline siderite matrix.

rounded, the smaller angular and deeply corroded. The ooliths vary much in diameter to a maximum of 0·5 mm. and in nearly all the concentric structure is very conspicuous. A few ooliths are double, two partly developed individuals being enclosed in a single outer envelope. The matrix consists of pale brown, very fresh siderite in crystals up to 0·65 mm. long, but not poecilitic, as in the better developed Black Oolites of Sandsend and Great Fryup (Rastall and Hemingway, 1939). It is this recrystallized siderite which gives the crystalline appearance to the hand specimen.

Magnetite-Oolite, Rosedale (Plate XV A)

Only loose blocks of this rock may now be found, usually blue-black in colour and slightly oxidized. These specimens show some mineralogical variation and suggest that the original deposit was not

uniform. One type, apparently more common, shows many well-formed ooliths up to 0·6 mm. diameter, made up of pale green chamosite invaded with magnetite along the cleavage planes. The magnetite is in the form of vast numbers of octahedra from ·002 mm. to ·012 mm. in length, but usually nearer the smaller figure; these form thin zones which alternate with the chamosite, but which sometimes fuse to form a thicker layer. There is no uniformity in the degree of magnetite formation, which in adjacent ooliths may vary from a thin surface layer to almost complete replacement. Irregular radial cracks, formed by volume reduction during magnetitization are common in the ooliths and these are now filled with a chlorite or a carbonate. Some ooliths show evidence of crushing after magnetitization, probably also consequent upon volume reduction. The nuclei are oolite fragments, unmagnetitized collophanite grains, and brown irregularly limonitized grains of doubtful origin.

The cement was originally a chloritic mineral, chamosite in part, which may now be magnetitized, but which is largely replaced by large poikilitic plates of siderite with a vague radial arrangement. Some ooliths are heavily carbonated with both broad concentric bands or irregular patches of siderite, while in extreme cases an oolith may be entirely replaced with siderite leaving only a magnetite rim.

A second, less common type is characterized by the complete absence of carbonate minerals. The ooliths are either converted to magnetite or concentrically zoned with alternating magnetite and chamosite. The nucleus is a warm golden brown chlorite, very finely crystallized and only weakly birefringent, usually giving only mass polarization effects. The matrix is entirely chloritic, fairly coarsely crystalline, with rouleux and vermiform aggregates. Some of this is chamosite, but a pale yellow chlorite with strong pleochroism and higher birefringence is also present.

A conspicuous feature of all slices examined is the absence of detrital grains. In this the Rosedale magnetite-oolite is unlike any of the Inferior Oolite ironstones of this region and more closely related to those of Yeovilian age.

The green mineral described by Hallimond (1925, p. 75) is seen in a slice of an oxidized specimen, where it consists of hexagonal plates separated by layers of some yellow mineral, like a honeycomb. As these structures are seen only with a quarter-inch objective, the nature of the minerals concerned has not been determined. The matrix of the fresh specimen also encloses flakes of a blue-green chloritic mineral which Hallimond identifies as thuringite (?). The colour is more blue than any chamosite known to us, and the pleochroism and birefringence stronger. A somewhat similar mineral, but orange brown, is described on p. 271.

It is hoped to examine the chlorites in this rock in detail at a future time, and it is sufficient now to confirm Hallimond's determinations, and mention some others, emphasizing that the chlorites are, in the main, different from what has been met with elsewhere in this investigation.

Our best thanks are given to Dr. L. R. Cox and Dr. L. F. Spath, of the British Museum (Natural History), for the identification of fossils quoted in this paper : to Mr. W. Anderson, of the Geological Survey, for assistance with mine and bore-hole records ; and to Mrs. E. F. Dickins for permission to quote from the log of the Crosscliff bore.

Conclusions

1. The tracing of the beds of the Lias-Oolite junction in north-east Yorkshire has been continued southwards into Farndale and Rosedale, where the distribution and succession follow, in the main, those of upper Eskdale. The Yeovilian strata are separated from the Dogger (s.l.) of the earlier writers (Fox-Strangways, Reid, and Barrow, 1885 ; Lamplugh, 1920, etc.). The term Dogger (s.s.) is restricted to those marine beds at the base of the Inferior Oolite of Yorkshire. In the area under consideration they rest unconformably upon several horizons in the Upper Lias and they underlie the Lower Deltaic Series.

2. On field evidence the low-grade ironstones (chamosite-siderite oolites) once worked at Rosedale East Mines and Sheriff's Pit and hitherto regarded as of Dogger (Inferior Oolite) age, are shown to be late Yeovilian age (*dispansum* or post-*dispansum*). These rocks are unknown elsewhere in Yorkshire. Lithologically, the ironstone from Rosedale East Mines is closely similar to Middle Lias ironstones of the Cleveland ironstone field further north.

3. The original boundaries of the sedimentational basin of the Rosedale ironstone did not extend far beyond the present limits of Rosedale. To the northern part of the dale pebble beds at this horizon indicate shallows where no ironstone was laid down, while the increasing proportion of detrital grains in the ironstones of southern Rosedale probably indicate a shore line in that direction. The ironstone thus represents the final depositional phase in the silted-up Liassic sea.

4. The two worked ironstones are now preserved in two of the several shallow, elongate tectonic basins of Caledonoid trend and pre-Dogger age. It appears probable that the structural basins, with their complementary anticlines were forming during the deposition of the ironstones, because the preservation of the thick wedge of Yeovilian chamosite-mudstone in the Hollins Basin could only result from downfolding during deposition. Further, the lithological

individuality of each of the ironstones suggests that each was precipitated in an area which was developing its own facies characteristics, though not necessarily completely separated from the other ironstones. The rising anticlines may well have provided such partial barriers.

Other similar but shallower structural basins are found in other parts of Rosedale, as well as Farndale and Great Fryup, and although these hold ironstones they are not of economic value. What was originally believed to be a single north–south pre-Dogger structural basin occupying the Fryup, Danbydale, Rosedale, and parts of adjacent dales is demonstrated to be a series of Caledonoid folds mainly arranged *en echelon* along a north–south line. Yeovilian rocks are now proved to occupy more than 55 square miles in this part of Yorkshire.

5. Ironstone pebbles, subsequently phosphatized, were eroded from the crests of pre-Dogger anticlines which separated the depositional basin into smaller structural basins; these pebbles contributed to the basal pebble bed of the Dogger (Inferior Oolite), together with other phosphatized Liassic calc-mudstones.

6. Marley's field evidence concerning the distribution of the Rosedale magnetite-oolite is reconsidered. The oolite is accepted as filling two channels cut in the Liassic surface, which pre-date at least a part and probably all the Dogger. This oolite is not believed to be contemporaneous with the Bilsdale channel fillings.

7. The Dogger (s.s.) rests unconformably upon truncated Yeovilian and Whitbian rocks and the Rosedale magnetite-oolite.

8. The marine Rosedale Sandstone is defined. Its distribution suggests that the downwarping over the ironstone basin continued into Inferior Oolite times.

9. The Black Shales continue south from upper Eskdale as the most valuable mapping horizon in the Dogger. These shales are now grouped as a part of the Blakey Series.

10. Facies variation is recognized in the main sandstone of the Dogger, which is here named, with the underlying Black Shales, the Blakey Series. The Green Flags, the Woodhead Scar sandstone, the Ajalon Series, etc., hitherto regarded as successive beds, are recognized only as facies variants of the upper part of the Blakey Series.

The distribution of these facies suggests that shallow water lay over Northdale, where the pebbly and ill-graded Ajalon facies was deposited. Deeper water lay to the west and north-west, where finer-grained, well-bedded, and well-graded rocks were laid down.

11. The petrography of the outstanding rock types is described. Micro-slumping and spastolithization are common in some of the oolitic ironstones and are regarded as evidence of contemporaneous

deformation of the sediments. Subsequent magnetitization in the magnetite-oolite is recognized, as well as the much commoner sideritization of the ooliths and detrital constituents of all the ironstones. The importance of siderite in all the rocks of the Lias-Oolite junction in this region is emphasized.

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PLATE XIII

A.—Photomicrograph of chamosite-oolite, Rosedale East Mines, Rosedale, Yorkshire, × 40. Chamosite ooliths with fair to poor concentric structure, all showing corrosion and incipient sideritization. The matrix is finely crystalline siderite, slightly limonitized. The whiter areas are shell moulds.

B.—Photomicrograph of chamosite-oolite, crags near adit to Sheriff's Pit, Rosedale, × 40. Chamosite ooliths (grey) showing spastolithization and sideritization. The matrix is coarsely crystalline siderite (white), now part limonitized (black).

PLATE XIV

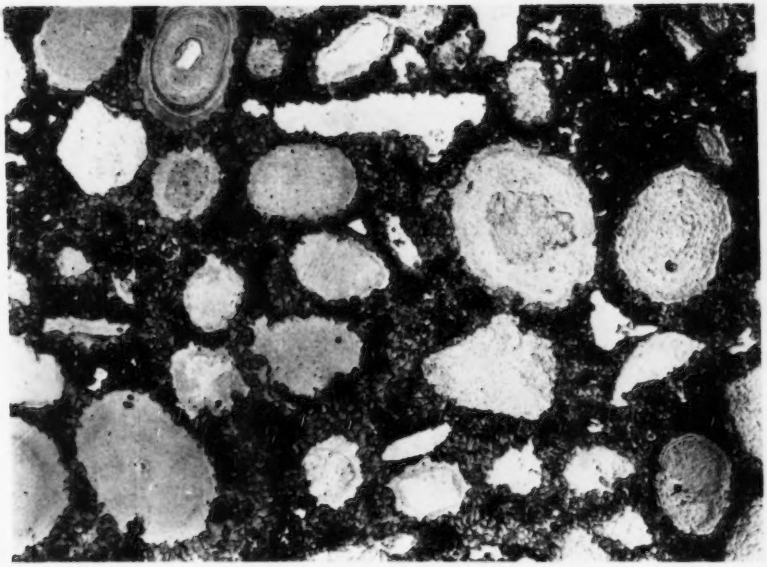
A.—Photomicrograph of chamosite-oolite, north wall of Kitching's Deposit, 600 yards W.N.W. of High Hollins Farm, Rosedale, × 40. Chamosite ooliths (grey) with good concentric structure, showing the development of spastoliths in several stages. The matrix is a sideritized chamosite mudstone, limonitized (black) by recent weathering, with quartz-mica silt.

B.—The same, showing micro-slumping in the oolite-free fraction of the sediment.

PLATE XV

A.—Photomicrograph of magnetite-oolite. Loose block near Kitching's deposit, Rosedale, × 40. Magnetite-chamosite-carbonate ooliths in which magnetite (black) alternates with chamosite and carbonates. The carbonates may be in optical continuity with the matrix.

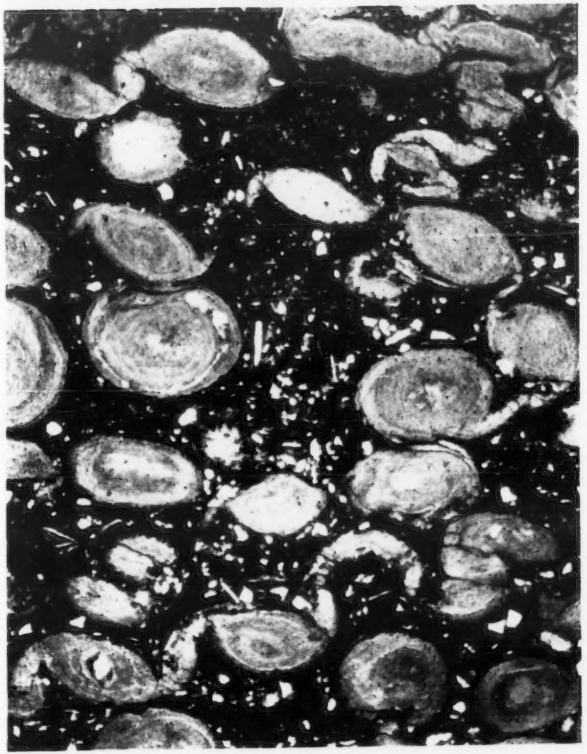
B.—Photomicrograph of chamosite-oolite, loose block near Rosedale East Mines, Rosedale, × 24. Siderite rhombs (grey) line the inner wall of a gastropod shell and fill its apex. A single crystal of calcite infills and replaces the shell. Limonitized siderite forms the matrix of the ironstone.



A

B

PHOTOMICROGRAPHS OF ROSEDALE IRONSTONES.



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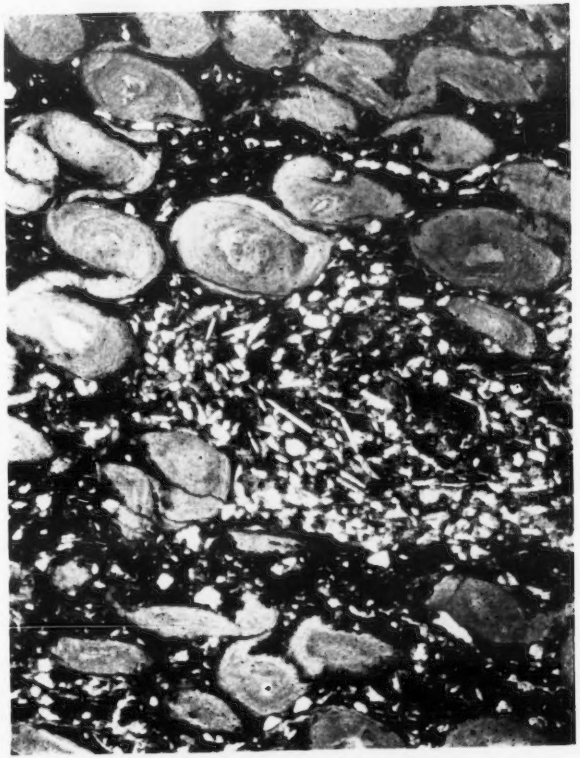

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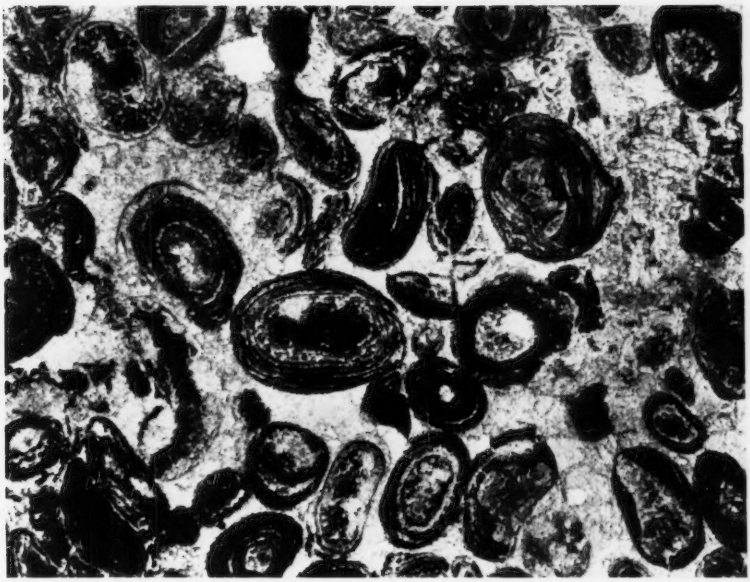
PHOTOMICROGRAPHS OF SPASTOLITHS AND MICROSLUMPING IN YEOVILIAN IRONSTONE, ROSEDALE, YORKSHIRE.



A

PHOTOMICROGRAPH OF MAGNETITE-OOLITE, ROSEDALE.

B

PHOTOMICROGRAPH OF GASTROPOD IN EAST MINES IRONSTONE, ROSEDALE.

Lineation in Moinian and Lewisian Rocks of the Northern Highlands of Scotland

By F. C. PHILLIPS

(PLATES XVI AND XVII)

ABSTRACT

It has recently been reaffirmed, on the basis of evidence derived from published maps, that in the Moine schists the south-easterly plunging lineation appears to increase in intensity as the Moine thrust area is approached. This statement is not in accordance with facts observable in the field and is a false premise on which to base the conclusion that thrusting and lineation are related. A further fact of vital significance in relation to such a conclusion is the widespread development of a similar lineation, plunging south-easterly and likewise expressive of a girdle fabric, in unmoved Lewisian rocks of the foreland.

STUDY of the structural petrology of the Moine schists has established that a girdle fabric is of widespread occurrence throughout this metamorphic assemblage. Muscovite and biotite are commonly orientated in simple girdles of varying degrees of completeness, whilst quartz diagrams show either a simple girdle or intermediate types transitional to a well-developed two-girdle arrangement (Phillips, 1937, 1945). The axis of the girdle is commonly marked by a megascopic lineation, mainly defined by the orientated arrangement and elongated habit of the micas. Over wide areas, this lineation plunges in a south-easterly direction. Though controversy at present centres around the genetic interpretation to be placed upon this lineation and its associated grain-fabric, the facts summarized in this paragraph are probably not questioned by any petrologist familiar with the rocks of the Northern Highlands.

A valuable contribution to the study of lineation in general is afforded by a recent memoir by E. Cloos (1946), a publication for which all structural petrologists will be grateful. An annotated bibliography covering a period of over a century is appended to a critical review which displays clearly the complexity of some of the problems involved. In the course of this review, several references are made to the distribution and possible significance of lineation in the Scottish Highlands. Progress must be founded upon a basis of established facts, and it is because I believe that some of the statements in this review are not in accord with present factual knowledge that I wish to comment upon them.

On p. 3 it is stated that " In Scotland lineation is well known as 'rodding' . . . and is shown in maps and described from many localities. Its intensity appears to increase generally as the Moine thrust area is approached ". In Plate 9, a map of the Assynt region is reproduced from parts of 1 in. map-sheets 101, 102, 107, and 108.

Commenting on this map, the author writes " Most of the lineation symbols are near the thrust planes and mostly in the area of crushed rock " (p. 27), and " Lineation is most pronounced in the vicinity of the thrust planes " (p. 28). At first sight, it may well appear that the published 1 in. sheets support such a generalization ; whilst there are many lineation symbols on such sheets as 114, 108, 101, 102, 92, and 82 covering the area adjacent to the outcrop of the thrust, there are none at all on sheets such as 115, 109, or 83 to the east.

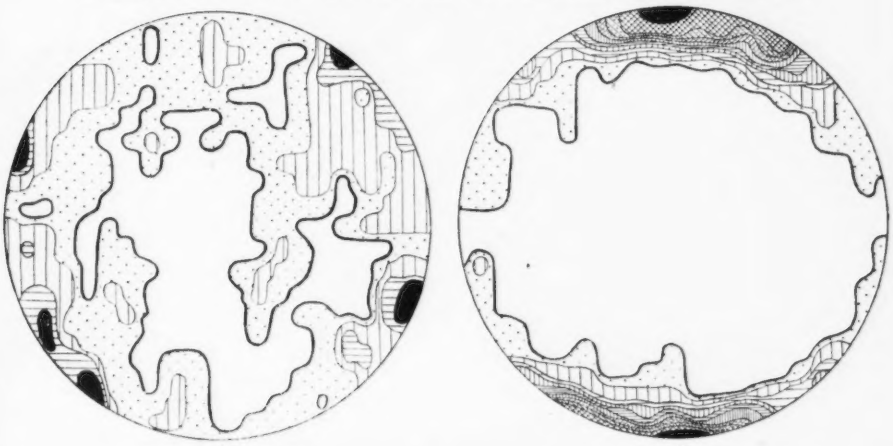
This distribution of symbols on the published maps, however, unfortunately does not afford an entirely reliable guide, since the absence of symbols from particular sheets does not mean that lineation cannot be observed in these areas in the field. Whilst some of the surveyors, notably C. T. Clough and those who were trained under him, were fully alive to the importance of this feature (see, for example, the many careful descriptions of linear structures in the memoir on sheet 93, The Geology of Ben Wyvis, etc., 1912, in a series of paragraphs all over the initials C. T. C.), others mapped only the strike and dip of the schistosity. On sheet 82 there are many symbols, on the adjacent sheet 83 to the east none at all. At various times I have examined the Moinian rocks over wide areas, from Fair-aird Head and Bettyhill in the north, southwards to the Great Glen, and to Sleat in Skye. Excluding material from the areas occupied by injection-complexes, a clear lineation is visible in about two-thirds of the specimens collected ; in a random sample of fifty specimens, covering a range from psammitic rocks with very little mica to highly pelitic types, thirty-two show a lineation sufficiently marked to be used in orientating thin sections cut from the hand-specimen. Good examples can be studied in the field at the following localities selected because they lie at distances between 20 and 35 miles east of the outcrop of the Moine thrust :—

East side of Loch Shin, north-west of Lairg, sheet 102.
Between Bonar Bridge and Invershin, sheet 102.
In the Blackwater river, near Garve, sheet 93.
West of Struy, Strath Glass, sheet 83.
North of Invermoriston, west side of Loch Ness (sheet 73, unpublished).

It is, of course, well known that a lineation of similar type to that under discussion is also developed extensively south of the Great Glen (see, for example, Anderson, 1948), both in rocks generally correlated with the Moinian and in members of the Dalradian assemblage. The problems here, however, are more complex, involving for example the development in places of a superposed lineation of different type, and the area will be excluded from the present account. Even with this exclusion, I do not believe that the facts of the distribution of lineation throughout the Moinian support the

generalization that lineation increases in intensity towards the outcrop of the thrust. The arguments advanced by Cloos " Thus the general conclusion seems justified that these structure elements are due to north-westward movement along thrust planes " (1946, p. 3), and " This (distribution of lineation symbols) indicates that thrusting and lineation are related, and, if thrusting is towards the north-west, the lineation in that direction is closely related to that movement " (p. 27) appear to be based on false premises.

Thus far, reference has been made only to rocks mapped as belonging to the Moinian assemblage. Rocks assigned to the Lewisian occur mainly in the foreland region, on the mainland north-west of the outcrop of the Moine thrust and in the Outer Hebrides, as a complex



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TEXT-FIG. 1.—Biotite-epidote-oligoclase gneiss, ½ mile north-west of Laxford Bridge. 250 quartz. Max. : 4%.

TEXT-FIG. 2.—250 biotite in same slide as Text-fig. 1. Max. : 14%.

largely composed of orthogneisses but including also some paragneisses and paraschists. This fundamental complex is cut by a series of intrusions, and is unconformably overlain in places by Torridonian and Cambrian sediments. South-east of the thrust, rocks mapped as Lewisian are found both as overthrust masses within the belt of complication (Peach and Horne, 1930, p. 46), and also as supposed " inliers " within the Moine area. The peculiar relationships revealed in places by the mapping have caused doubt to be cast upon the validity of the factors used in separating supposed Lewisian from Moinian rocks in some areas (Read, 1934, pp. 312, 316), and in Central Sutherland at least no evidence of discordance between rocks of Lewisian type and the Moine Series could be detected (Read, 1931,

p. 69). In Morar, Richey and Kennedy (1939) considered that they could distinguish a structurally lower group, separated from the Moinian rocks by a line of discordance, which they named provisionally Sub-Moinian. It has recently been suggested, however (MacGregor, 1948), that the factors on which this separation was based are invalid, and that the Sub-Moine rocks of Morar may constitute a lower part of the Moine Series associated with hornblendic orthogneisses. In view of these present obscurities, the term " Lewisian " in the account which follows is to be understood merely to imply rocks so coloured on the published maps. Examination of such map-sheets as 107,

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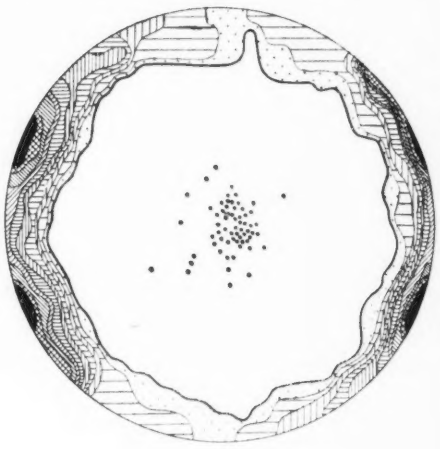

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TEXT-FIG. 3.—Hornblende-biotite gneiss, 1 mile north-east of Lochinver. 250 biotite. Max.: 14%.

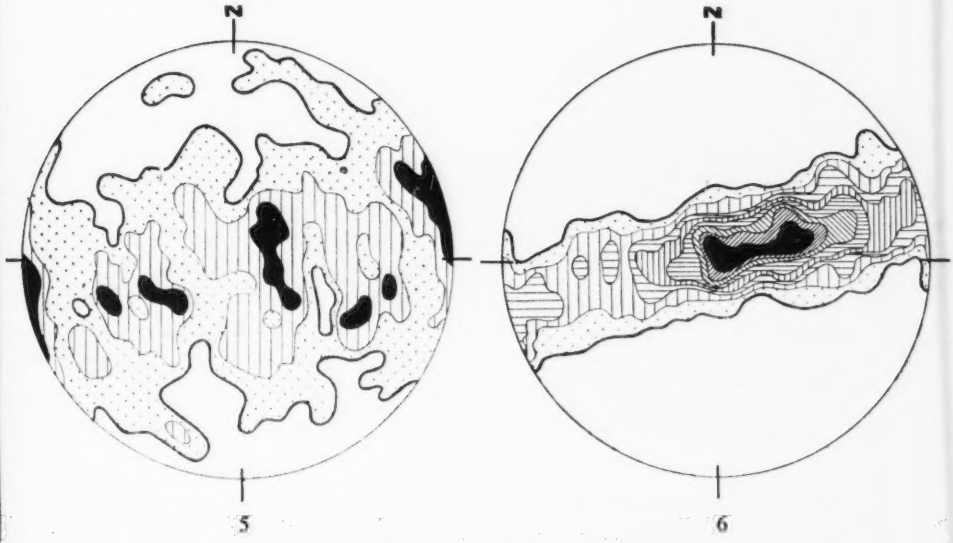
TEXT-FIG. 4.—Hornblende-schist, 1½ miles south-east of the summit of Slioch. 126 prismatic cleavages of hornblende and 63 corresponding *z*-axes. Max.: 12%.

101, 92, and 91 will at once reveal that a lineation, sufficiently pronounced to attract attention in the field, is present in many Lewisian rocks. Indeed, nearly fifty symbols which lie within the Lewisian of the foreland structurally below unmoved Torridonian, and not within the area occupied by Moinian rocks, are shown in Cloos' reproduction, pl. 9. With few exceptions, these symbols show a south-easterly plunge, and examination in the field has confirmed that, over a wide area of the foreland and also in rocks mapped as displaced Lewisian masses and in some at least of the supposed inliers, a south-easterly plunging lineation is a characteristic feature of the fabric.

As already briefly stated (Phillips, 1947), measurements on orientated sections have proved that in these rocks, as in the Moine schists, the

direction of lineation is normal to a girdle of the grain-fabric. Girdles are shown by all the readily measurable component minerals of the fabric, such as quartz, muscovite, biotite, and hornblende, in rock types varying from granitic gneisses to hornblende-plagioclase gneisses and hornblende schists. That such fabrics prevail may, indeed, be deduced from the remarkable descriptions published by Teall over forty years ago. Of the Loch Maree mica-schists he wrote (Peach and Horne, 1907, pp. 75–6) :

" The flat surfaces of schistosity possess a silky lustre and show



TEXT-FIG. 5.—Biotite-epidote gneiss, Meall an Spardain. 300 quartz. Max. : 3%.

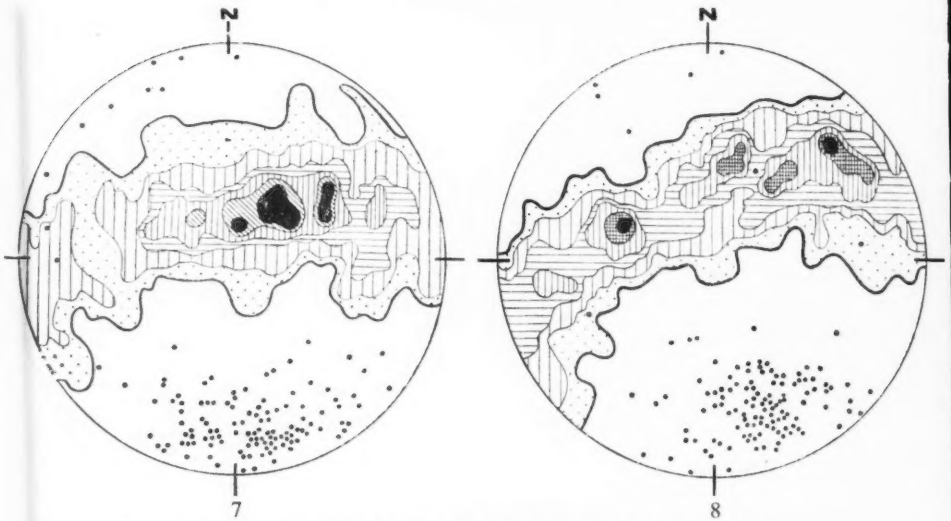
TEXT-FIG. 6.—250 biotite in same slide as Text-fig. 5. Max. : 8%.

a fine parallel striping . . . . The individuals of quartz are irregular in outline and variable in size . . . a slight tendency to flattening in the direction of schistosity and elongation in the direction of striping may be observed. In microscopic structure there is a marked contrast between the section at right angles to the schistosity and parallel to the striping, and that at right angles to the schistosity, and also at right angles to the striping. The former shows a perfect parallel structure due to the arrangement of the mica-flakes ; the latter shows the mica-flakes lying at all angles and gives unmistakeable evidence of minute puckering."

In quartz-magnetite rocks he observed the positions of maximum

and minimum illumination in quartz aggregates between crossed nicols. Of the Poolewe district he wrote (p. 97) :

" Near the centre of the district, south of Poolewe, in which Mr. Clough has proved the existence of a kind of anticlinal structure in the arrangement of the dyke-like masses, the hornblende schist is linearly foliated, parallel with the pitch of the folds. This is well seen in a specimen from a point five-eighths of a mile north of Meall an Spardain. The rock is essentially composed of green hornblende



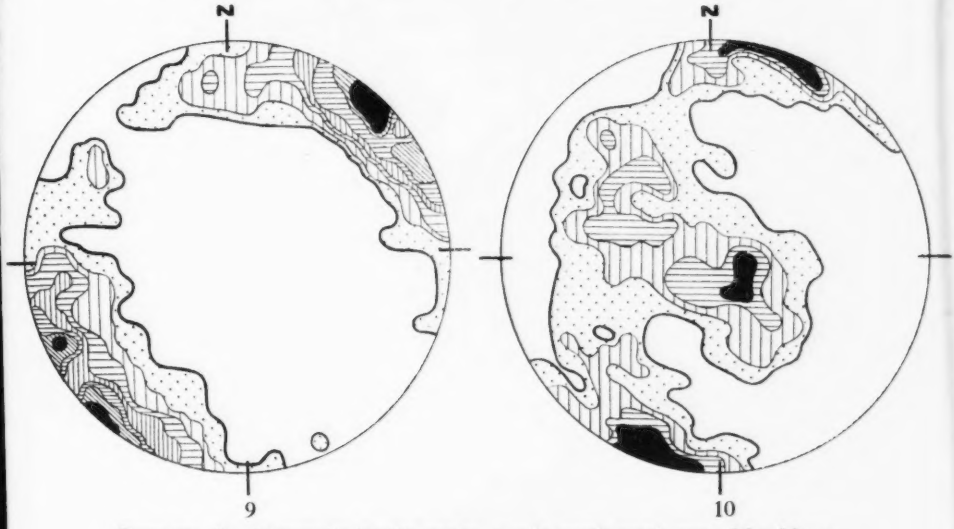
TEXT-FIG. 7.—Hornblende gneiss, Meall an Spardain. 250 prismatic cleavages of hornblende and 125 corresponding *z*-axes. Max. : 6%.

TEXT-FIG. 8.—Hornblende gneiss same locality as Text-fig. 7. 250 prismatic cleavages of hornblende and 125 corresponding *z*-axes. Max. : 6%.

and a somewhat basic oligoclase. Quartz and a few grains of colourless sphene are also present. Two sections have been prepared ; one parallel to the direction of foliation, the other transverse (Pl. XLIX, Figs. 1 and 2). A comparison of the two shows that the individuals of hornblende, though irregular in outline, are arranged with their vertical axes approximately parallel with the direction of foliation, and consequently with the pitch of the folds in the district. The grains of oligoclase are irregular in outline and of approximately equal dimensions in the different directions. The rock has not been subjected to mechanical deformation since the formation of the existing minerals. There are no signs of cataclastic action. These facts prove that the rock was either intruded during movement and consolidated in its present form, or that a previously

formed rock was entirely recrystallized under the influence of the stresses which produced the 'rodded' or 'mullion-structure' of the district."

Text-figs. 1–4 are examples illustrating the results of measurements on sections cut normal to a megascopic lineation, in specimens from localities scattered between Loch Laxford in the north and Gairloch some 50 miles south-south-west. The attitude of the girdles in space, corresponding to the predominating south-easterly plunge of the



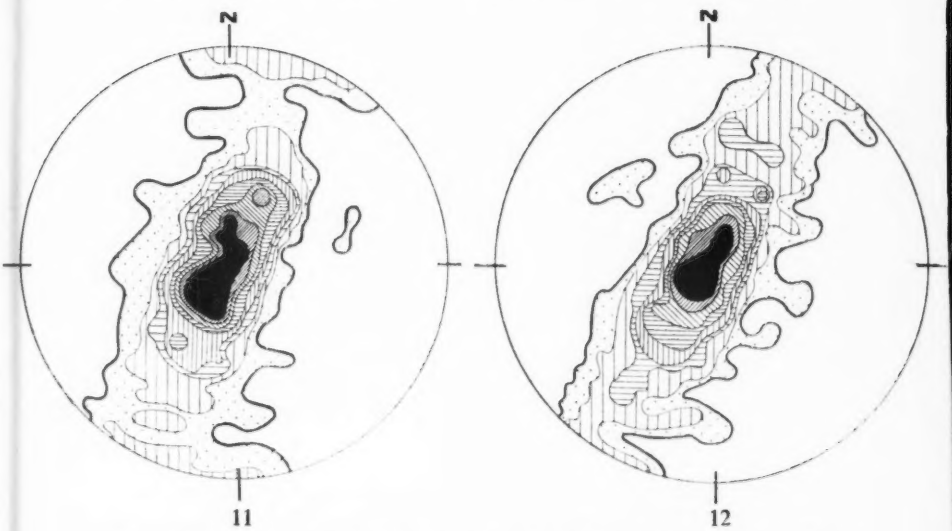
TEXT-FIG. 9.—Muscovite-biotite gneiss, ½ mile north-north-east of Lochinver. 250 muscovite. Max.: 8%.

TEXT-FIG. 10.—Muscovite-biotite-epidote gneiss, Knock Bay, Sleat, Skye. 207 quartz. Max.: 4%.

lineation, can be appreciated most readily from diagrams rotated to their true geographical orientation. Text-figs. 5–9 illustrate in this manner a further selection of measurements. Text-figs. 10–12 provide an example of the closely similar conditions prevailing in rocks mapped as displaced Lewisian within the overthrust region above the Moine thrust in Sleat, Skye; the micas occupy well-defined girdles, but it is of interest to note that the quartz diagram shows an incipient development of a second girdle, a feature which, where it is developed in Moinian rocks, I have tentatively related to overprinting (Phillips, 1945, p. 218).

These diagrams and descriptions thus show that an argument which seeks a direct correlation between the distribution of lineation in Moinian rocks and the outcrops of the overthrusts is still further

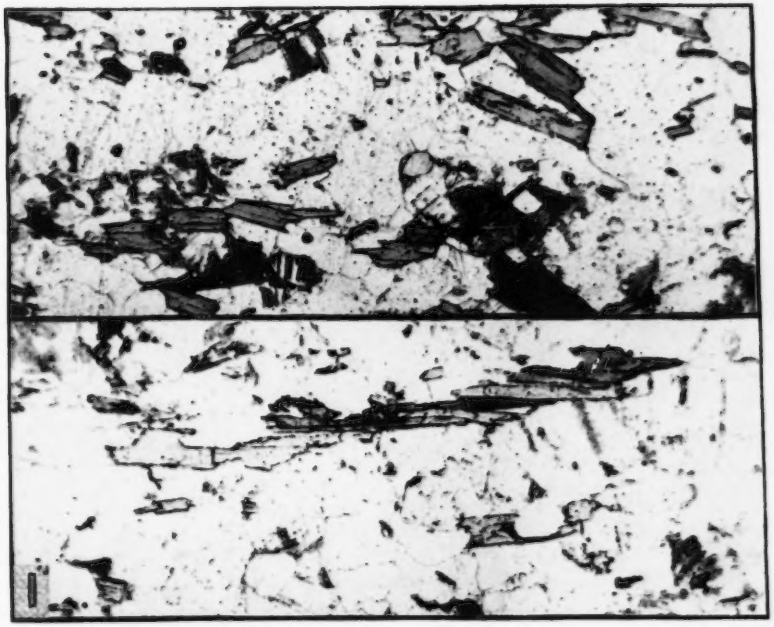
weakened by the widespread development of a closely similar lineation in Lewisian rocks, both of the foreland and in displaced masses. The purpose of this communication is to place these facts on record, without proceeding at this stage to further consideration of possible genetic interpretations of the lineation and associated fabric. For that reason I have refrained from using descriptive terms, such as *a*- and *b*-lineations and B-tectonites, to which genetic significance is now attached in the literature of structural petrology. Even, however, if the validity should eventually be established of the sweeping conclusion reached by Anderson (1948, p. 125) that " a rather fundamental mistake has

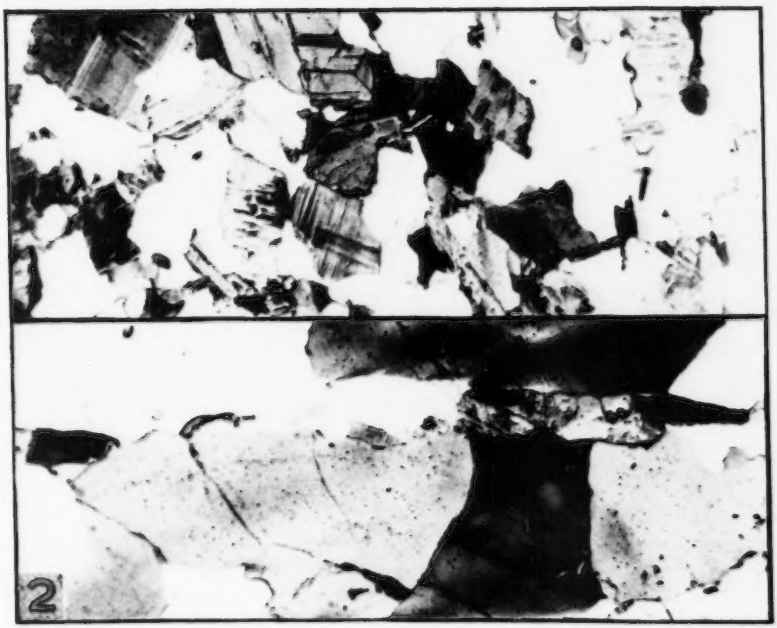


11 12

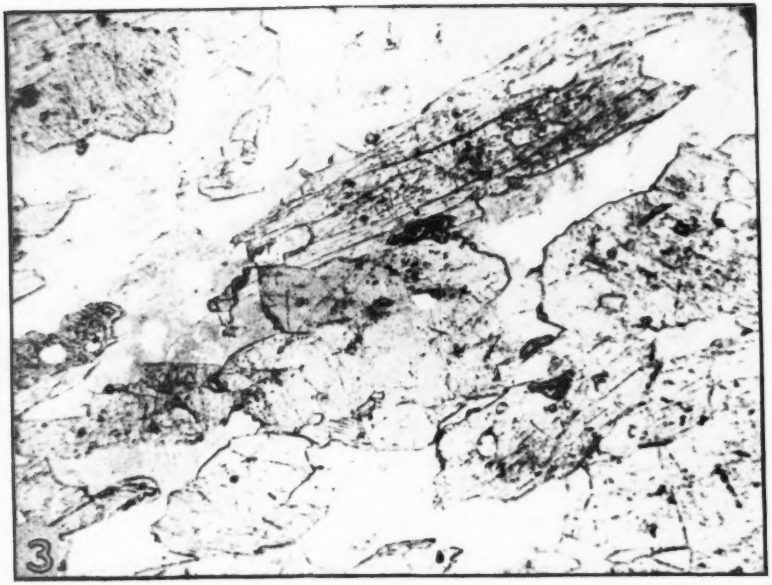
TEXT-FIG. 11.—250 muscovite in same slide as Text-fig. 10. Max.: 10%.
TEXT-FIG. 12.—250 biotite in same slide as Text-figs. 10 and 11. Max.: 10%.

hitherto usually been made in the interpretation of petrofabric structures ", and lineation of this type should be proved to be always parallel to direction of shear (" direction of transport "), the problem presented by the close resemblance between the fabrics of Moinian and of Lewisian rocks still calls for solution. I am unable meanwhile to follow the argument put forward by Shackleton in support of his suggestion (discussion on Anderson, 1948, p. 128) that the lineation in the Lewisian foreland is parallel to the direction of pre-Cambrian movements—an interval of approximately 10^9 years between pre-Cambrian and Caledonian orogenies does not seem to me so short as to justify the statement that " the whole system of movements *suddenly* changed their direction through a right angle ".





FABRIC OF LEWISIAN ROCKS.



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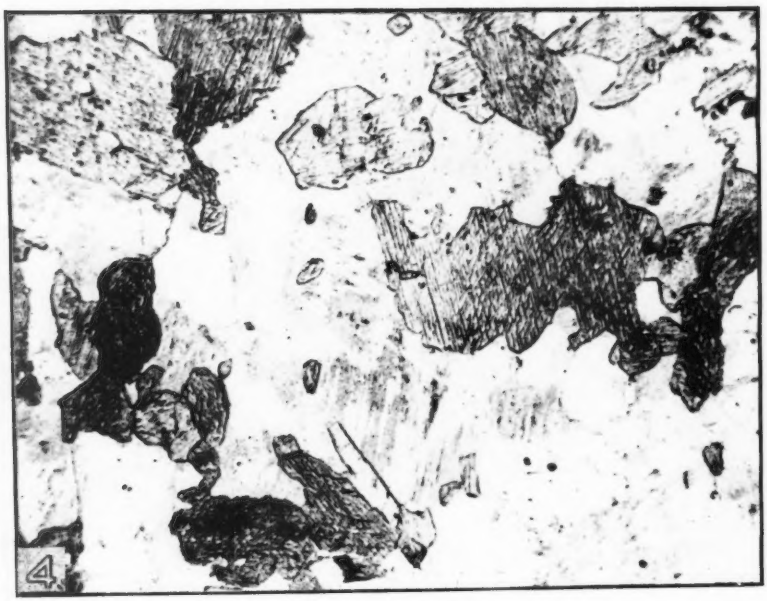

2

FABRIC OF LEWISIAN ROCKS.

Nor is a solution to be found by postulating a late recrystallization and reorientation of the quartz, the fabric of which would thus be related only to the " latest phases of dislocation . . . only a component of the entire movement and not representative " (Cloos, 1946, p. 28 ; compare also Tilley, discussion on Phillips, 1937, p. 619, and on Anderson, 1948, p. 129). The problem presented by the Moinian and Lewisian rocks alike is that of a fabric essentially homotactic in respect of all the essential minerals—quartz, muscovite, biotite, hornblende. With the possible exception of certain minor features, (Phillips, 1945, p. 215) it is the whole metamorphic fabric of these rocks which is involved. Though the facts ascertained may be awkward in relation to some particular tectonic synthesis, it is our task to explain these facts and not merely to explain them away.

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EXPLANATION OF PLATES

PLATE XVI

Textures of Lewisian rocks. × 18.

In each figure the upper strip is from a section normal to the lineation and the lower from a section parallel to the lineation.

FIG. 1.—Biotite-epidote-oligoclase gneiss, ½ mile north-west of Laxford Bridge. Polarizer only.

FIG. 2.—Feldspathic gneiss with biotite and epidote, Meall an Spardain. Crossed nicols. The section parallel to the lineation shows the grain elongation in quartzose bands.

PLATE XVII

Textures of Lewisian rocks. × 18.

FIG. 3.—Hornblendic gneiss, 2½ miles north-east of Gairloch. Section normal to the lineation.

FIG. 4.—Same rock as Fig. 3, section parallel to the lineation.

The Age of Uraninite and Monazite from the Post-Delhi Pegmatites of Rajputana

By ARTHUR HOLMES (*University of Edinburgh*)

With Chemical Analyses by A. A. SMALES (*I.C.I. Research Dept., Billingham, Co. Durham*), and Isotopic Analyses of Lead by W. T. LELAND and A. O. NIER (*University of Minnesota, Minneapolis, U.S.A.*)

ABSTRACT

Uraninite and monazite collected by Dr. H. Crookshank from pegmatites occurring respectively at Bisundni and Soniana (Rajputana) have been analysed for U, Th, and Pb by Mr. A. A. Smales, and the isotopic constitution of the lead separated from each mineral has been determined by Dr. W. T. Leland and Prof. A. O. Nier. The three ages calculated from the uraninite ratios AcD/RaG, RaG/U and AcD/U are 740, 733, and 733 m.y. The monazite is considerably altered but the corresponding ratios indicate that its age lies between 700 and 865 m.y., which is consistent with the more reliable estimate determined from the uraninite. It is shown from tectonic evidence that the Delhi orogenic belt is younger than the Satpura belt (previously dated at about 900 m.y.) and that both are younger than the Aravalli and Dharwar belts.

I. INTRODUCTION

THREE years ago I heard that a small pocket of uraninite had been discovered in a pegmatite occurring in Rajputana. Realizing the importance of this find from the point of view of dating one of the best known Pre-Cambrian orogenic belts of India, I addressed an inquiry to Dr. W. D. West, Director of the Geological Survey of India, and suggested that the age of the uraninite should be determined. Dr. West at once sent me some samples of the uraninite, together with several large fragments of monazite crystals from another pegmatite of the same suite, and at the same time he put me in touch with Dr. H. Crookshank who had discovered and collected the minerals. I then approached Dr. R. Holroyd, Research Manager of Imperial Chemical Industries, Limited, Billingham Division, who, after consultation with Mr. W. C. Hughes, Chief Analyst of the Research Department at Billingham, commissioned Mr. A. A. Smales to undertake analyses of the two minerals for uranium, thorium, and lead. In each case Mr. Smales also prepared samples of lead—in the form of carefully purified lead iodide—for transmission to Professor A. O. Nier, who in the meantime had agreed to determine the isotopic constitutions of the two leads. It is a pleasure to express here my thanks to all these gentlemen for their willing and generous co-operation in this work. My own share has been to organize the joint investigation, to calculate the ages and discuss their significance in relation to Pre-Cambrian geology and, with the exception of Sections VI and VII, to write the paper.

II. Geological Setting

The Aravalli ranges, which cross Rajputana from Delhi to Gujerat in a general N.E.–S.W. direction, consist essentially of a synclinorium of more or less metamorphosed rocks belonging to the Delhi and Aravalli Systems. In certain localities the Raialo Series occurs between the two systems with unconformable junctions above and below. The Aravalli basal conglomerates lie unconformably on a gneissic complex, the more granitic parts of which are commonly correlated with the Bundelkhand "Gneiss" of the type area to the east. The general sequence is as follows (Coulson, 1933; Gupta, 1934; Heron, 1935; Krishnan, 1943) :—

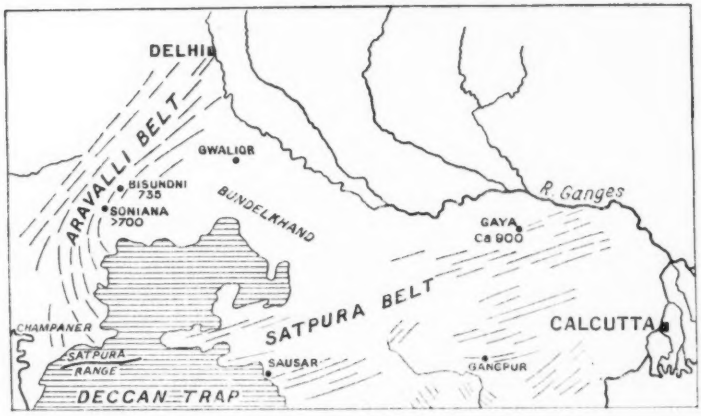
Delhi System	Pegmatites, aplites, and quartz veins. Granites (e.g. the Erinpura Granite). Dolerites, epidiorites, and hornblende-schists. *Ajabgahr Series.* Calcareous and argillaceous beds *Alwar Series.* Quartzites and arkosic grits	and metamorphic equivalents.
	Raialo Series. Schists, marbles, and quartzites.	
Aravalli System	Dolerites and epidiorites. Pegmatites, aplites, and quartz veins. Granites and migmatites. Epidiorites, hornblende-schists, and serpentine-chlorite-rocks Shales, limestones, quartzites Quartzites and grits Local basic volcanics	and metamorphic equivalents.
Gneissic Complex	Pegmatites, aplites, and quartz veins. Granites and migmatites. Paragneisses, amphibolites, and chlorite-biotite-schists.	

Three orogenic cycles appear to be represented in Rajputana, the Raialo Series, which is only about 2,000 feet thick, being probably part of the third, i.e. the Delhi cycle.

(i) The *Gneissic Complex* and the Bundelkhand granite and gneiss may possibly represent more than one cycle, as the various parts, exposed between successive belts of the Aravalli and Delhi rocks, have not as yet been satisfactorily correlated. As a whole, however, the complex has a N. or N.N.W. trend and it clearly forms a deeply denuded basement on which the later formations were deposited.

(ii) The *Aravalli Orogenic Belt* swings round in the south and follows a N.S. trend in the "Champaner Series" which has now been correlated with the Aravallis by continuous mapping (cf. Text-fig. 1). Further east the trend gradually changes to a N.N.W.–

S.S.E. direction as the Deccan trap is approached. This direction would carry the Aravalli Belt into the Dharwars which appear on the southern side of the Deccan traps. It is therefore tempting to correlate the Aravallis with the Dharwars. However, it is equally possible that the Gneissic Complex may be, or may include, a correlative of the Dharwar cycle, and until appropriate radioactive age determinations have been made, all such suggestions remain purely speculative. It is interesting to notice, however, that the ancient rocks of the Satpura Range, which rise above the present surface of the Deccan traps, have a roughly E.–W. trend, which implies that they cut across the Aravalli Belt and are therefore younger. These Satpura rocks are regarded



TEXT-FIG. 1.—Map showing the dominant trend lines of Pre-Cambrian orogenic belts in the northern part of Peninsular India. Numbers refer to the ages (in millions of years) of dated radioactive minerals.

as a continuation of the Sausar and Gangpur Series of the vast Pre-Cambrian area lying to the east of the northern part of the Deccan traps.

(iii) The *Delhi Orogenic Belt*, in the area under consideration, is superimposed on the Aravalli belt and has the same regional trend (see map in Heron, 1935). Further west, however, the Delhi rocks do not share in the southward turn of the Aravallis but appear to continue straight on towards Kathiawar (cf. Krishnan, 1943, p. 139). As a test of the continental drift hypothesis it will be of great interest to see if continuations of the Delhi and Satpura belts can eventually be recognized on the other side of the Arabian Sea. In India the Delhi and Satpura belts fail to meet and their relative ages cannot be determined geologically. The evidence from radioactive minerals presented in this

paper indicates, however, that the Delhi is the younger. See p. 298 for further discussion.

Each of the three orogenic cycles of Rajputana ends with a display of pegmatites and, since the younger pegmatites also occur in the older rocks, it is not always easy to assign its proper age to any particular occurrence. Pegmatites known to be of pre-Delhi age are medium-grained and often foliated and disturbed by later movements ; they are characteristically lacking in accessory minerals other than occasional flakes of muscovite. Most of these older pegmatites appear to be of post-Aravalli age, but some undoubtedly belong to the Gneissic Complex, since they have contributed to the basal conglomerates of the Aravalli (Coulson, 1933, p. 18). The post-Delhi pegmatites are coarse-grained, massive and unfoliated rocks which often carry considerable quantities of muscovite and tourmaline and sometimes of apatite and beryl. They vary in form from small lenses a few feet wide up to massive dykes which may be as much as a hundred feet across and a thousand feet long. They generally dip steeply at 70° or 80° and, though rare in the Alwar quartzites, they are commonly found in the mica-schists of the Ajabgarh Series (Heath, 1947). Exactly similar pegmatites also occur in the phyllites and mica-schists of the Aravalli System. Mica-rich pegmatites of this kind are distributed along a broad belt stretching from Gujerat to Delhi ; many of them are worked for mica, or have been in the past, and until recently some of them were also worked for beryl (Crookshank, 1947, pp. 4–5). Being obviously later than the regional metamorphism that has affected the Delhi schists and quartzites, this whole suite of pegmatites is regarded as of post-Delhi age.

The uraninite and monazite discovered by Dr. Crookshank were both found in pegmatites belonging to the post-Delhi suite. The occurrences will be described in detail by Dr. Crookshank in a forthcoming paper.

III. The Uraninite and its Age

The uraninite was collected from a large pegmatite occurring in biotite-gneiss at Bisundni, Ajmer-Merwara (25° 44′ ; 75° 9′ 30″). The pegmatite has been opened up for muscovite and beryl and is still being actively worked for mica. The uraninite and its associates occur in nodular masses in association with beryl and cleavelandite. The largest of the specimens sent by Dr. West from Dr. Crookshank's collection contains several black lustrous cores of uraninite up to 2 cm. or more across, surrounded by coalescing aureoles of bright red to yellowish red gummite (5–6 mm. wide) followed in turn by broader shells of up to 15 mm. across of dull yellow uranophane associated with a canary-yellow material that may be becquerelite or shoepite.

The boundaries between the black cores and the red and yellow zones appear to be sharp, but in thin section a rapid gradation of colour is seen. The canary-yellow mineral sends long veinlets of acicular crystals into the surrounding cleavelandite, which has clearly been metasomatically replaced. A few micaceous scales of autunite are embedded in the yellow shells. One specimen, which is part of a pseudomorph after feldspar, has a violet-coloured mineral (instead of gummite) between the uraninite and the uranophane ; this mineral resembles ianthinite (Shoep, 1927) but it has not yet been identified with certainty. In some of the smaller specimens the uraninite cores have almost disappeared and the yellow zone has widened at the expense of the red, indicating progressive replacement. There is nothing to suggest that the alteration is due to weathering. The massive appearance of the material and its replacement of feldspar suggest that it represents a late stage of alteration in the history of the pegmatite itself.

The uraninite cores of the largest specimen are seen in thin section to be perfectly fresh and free from fractures and veinlets. The cores from one half of the specimen were broken out and crushed into small pieces. Lustrous fragments free from adhering crusts of gummite were picked out and prepared for the analysis made by Mr. Smales (see p. 299). The lead isolated during the analysis was conveertd into pure lead iodide for transmission to Professor Nier. The results of the isotopic analysis carried out by Leland and Nier are recorded in Table I.

TABLE I

URANINITE, BISUNDNI, AJMER-MERWARA, RAJPUTANA, INDIA

Chemical Analysis (A. A. Smales) :

Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	*Apparent Age (m.y.)*
7·95	72·9	1·4	·107	·98	730

Isotopic Analysis of Lead (W. T. Leland and A. O. Nier) :

Isotopic Proportions	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
In Total Lead . .	<·001	100·00	6·39	·806
In Original Lead . .	(negligible)			
Per cent of Radiogenic Lead in Uraninite.		7·416 RaG	·474 AcD	·06 ThD

	$\frac{AcD}{RaG}$	$\frac{RaG}{U}$	$\frac{AcD}{U}$	$\frac{ThD}{Th}$
Ratios	·0639	·1017	·0065	·0429
Apparent Ages (m.y.) .	740	733	733	935

It will be seen that the uraninite is unusually poor in thorium. The crude age read from the family of graphs prepared by Wickman (1944) is 730 million years. The isotopic constitution of the lead is stated in proportions relative to Pb^{206} taken as 100. Since the proportion of Pb^{204} is less than ·001, it follows that the uraninite is practically

free from original lead, of which Pb^{204} (not being of radiogenic origin) is an index. Pb^{206} thus represents RaG, the end product of U^{238}; similarly, Pb^{207} represents AcD, the end product of U^{235}; and Pb^{208} represents ThD, the end product of Th^{232}. The " age " of the mineral, t_m, can be calculated independently from each of the three ratios RaG/U, AcD/U, and ThD/Th. The respective equations (Keevil, 1939) are :

$$t_m = 15{\cdot}15 \times 10^9 \log_{10}(1 + 1{\cdot}158\,\mathrm{RaG/U})\text{ years.}$$
$$t_m = 2{\cdot}37 \times 10^9 \log_{10}(1 + 159{\cdot}6\,\mathrm{AcD/U})\text{ years.}$$
$$t_m = 46{\cdot}20 \times 10^9 \log_{10}(1 + 1{\cdot}116\,\mathrm{ThD/Th})\text{ years,}$$

where the chemical symbols represent the percentages of the parent elements and of the isotopes of radiogenic lead now present in the mineral. A fourth value for t_m is given by the ratio AcD/RaG. This cannot be directly calculated from the ratio, but Wickman (1939) has calculated the values of the ratio for values of t_m up to 3,500 m.y. and has expressed the results graphically, so that, knowing the ratio, the value of t_m can be read off. If a mineral has remained unaltered, all four values for t_m should be in close agreement. For reasons that at present are not fully understood—though the extreme difficulty of determining Th with accuracy is certainly one of them—the " age " calculated from ThD/Th almost invariably differs considerably from the most probable age. The present example is no exception to this rule and, as usual, one can only set aside this particular age-value as being unreliable. The ages from RaG/U and AcD/U, however, are found to be in perfect agreement (733 m.y.). In such a case the age from AcD/RaG should theoretically also be identical and, indeed, the value actually read from Wickman's diagram (740 m.y.) differs no more than is to be expected in practice. Amongst old minerals such perfection as this is rare, the only comparable case being that of a uraninite from Ontario (Holmes, 1948*a*, p. 183). It is clear that the Bisundni uraninite is of exceptionally good quality as an index of age, and the age now assigned to it—735 $\pm$ 5 m.y.—may be given a place amongst the very few that can be accepted as of first-class reliability.

IV. The Monazite and its " Age "

The monazite was collected from a pegmatite at Soniana, Mewar State (25° 7′ ; 74° 40′), that was formerly worked for mica. This locality is marked on a geological map by Gupta (1934). The uraninite locality is about 50 miles to the north-east, just off Gupta's map.

The sample received consisted of large and small fragments of monazite crystals, some of which must originally have been several inches long. Most of the material was clean, apart from occasional adhering flakes of muscovite, but the fractured surfaces show evidence of patchy internal decomposition. The fresh-looking portions are

yellowish-brown and resinous, but these are veined and surrounded by duller material. Many smaller veinlets and fractures could be seen in thin section. After crushing, the most resinous portions, free from visible veins, were picked out and prepared for the analysis made by Mr. Smales (see p. 300). As before, the lead isolated during the analysis was converted into pure lead iodide and sent to Professor Nier. The results of the isotopic analysis by Leland and Nier are recorded in Table II.

TABLE II

MONAZITE, SONIANA, MEWAR STATE, INDIA

Chemical Analysis (A. A. Smales):

Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	*Apparent Age (m.y.)*
·525	·68	16·45	·0306	·04	620

Isotopic Analysis of Lead (W. T. Leland and A. O. Nier):

Isotopic Proportions	Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
In Total Lead	·008	13·58	1·03	100·00
In Original Lead *	·008	·14	·12	·29
	—	13·44	0·91	99·71
Per cent of Radiogenic Lead in Monazite.		·062 RaG	·0042 AcD	·457 ThD
	$\frac{AcD}{RaG}$	$\frac{RaG}{U}$	$\frac{AcD}{U}$	$\frac{ThD}{Th}$
Ratios	·0677	·0912	·0062	·0278
Apparent Ages (m.y.)	865	660	700	613

* The approximate isotopic proportions of ordinary lead formed about 700 m.y. ago is taken as

Pb^{204}	Pb^{206}	Pb^{207}	Pb^{208}
1	17·07	15·46	36·85

Chemically, this monazite is of interest in containing more Th and U than any other monazite hitherto analysed for age purposes (for list, see Holmes, 1948*b*, p. 120). On the other hand, as shown below, it contains less original lead than any other fully investigated monazite. The crude age read from Wickman's family of graphs is 620 m.y., which is considerably lower than the uraninite age, suggesting that the mineral has suffered loss of lead. The isotopic analysis confirms this inference.

The isotopic constitution of the lead in this case is stated in proportions relative to Pb^{208} taken as 100. The proportion of Pb^{204} is ·008, corresponding to the presence of ·002 per cent of original lead in the newly crystallized monazite. The isotopic constitutions of lead from three other monazites have been determined by Nier, Thompson, and Murphey (1941, p. 113), and from the proportion of Pb^{204} in each an estimate of the original lead can be similarly made. The results,

together with the present one, are given in the last column of Table III. These very minute amounts confirm the geochemical expectation that lead, apart from radiogenic lead, would be only a trace element in monazite.

TABLE III

PERCENTAGES OF ORIGINAL LEAD IN MONAZITES

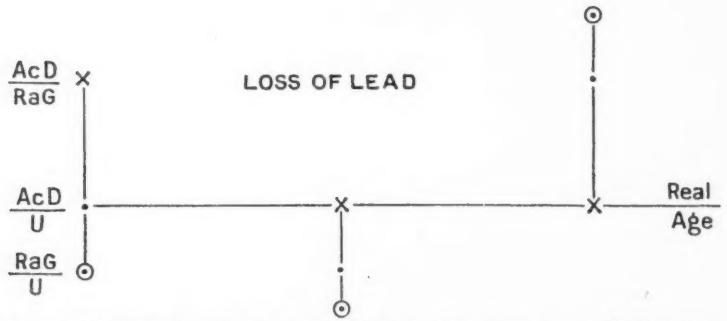
Locality of Monazite	Age in m.y.	Isotopic Proportions of Lead ($Pb^{208} = 100$)		Percentage of Lead in Monazite	
		Total	Pb^{204}	Total	Original
Huron Claim, Manitoba .	1985	113·721	·011	1·524	·013*
Mt. Isa, Queensland .	1200	106·891	·041	·285	·008
Las Vegas, New Mexico .	1330	111·378	·028	·372	·007
Soniana, India . .	735	114·618	·008	·525	·002

* As a result of misplacing a decimal point this figure is wrongly given as ·001 in Holmes, 1948*b*, p. 119.

In Table II the isotopic proportions of the original lead are subtracted from those of the total lead, the balances being the proportions of the radioactive isotopes RaG, AcD, and ThD. The respective " ages " are then calculated as indicated on p. 293. It will be noticed that the " ages " vary through a considerable range, a fact which testifies to the altered character of the mineral. The " ages " calculated from RaG/U, AcD/U, and AcD/RaG will of necessity depart considerably from the real age, according as the mineral has suffered loss of radon by gaseous diffusion, or loss or gain of uranium and/or lead (e.g. by weathering). For example, if part of the radon has been lost during the lifetime of the mineral, RaG will be deficient (Wickman, 1942). In this case the " age " from RaG/U will be too low, that from AcD/RaG will be too high, and, provided there has been no other alteration, the correct age will be given by AcD/U. The resulting sequence of " ages " is illustrated graphically in Text-fig. 2, which also shows the pattern of the results obtained when there has been loss of Pb (or gain of U) or loss of U (or gain of Pb). In these cases the age from AcD/RaG will be the correct one, if the alteration has been recent, since the ratio is independent of U and is unaffected by chemical changes involving Pb as a whole. And even if the alteration took place long ago the age is still very nearly correct (see Holmes, 1948*b*, Fig. 2, p. 121).

Applying these principles to the Soniana monazite it will be seen that the sequence of the " ages " corresponds to either loss of radon or loss of lead or both. The age from ThD/Th is too low and that points to loss of ThD. Now, since it is difficult to see how ThD could be lost without a corresponding loss of all the associated isotopes of

lead, it can be concluded that the mineral has suffered loss of lead. If this were all, the most probable age would be 865 m.y. However, it is easy to show that such alteration fails to account for the actual



TEXT-FIG. 2.—Diagram illustrating the effects of various types of alteration on the apparent ages of radioactive minerals calculated from AcD/RaG (crosses), AcD/U (dots), and RaG/U (dots and circles). The horizontal line represents the true age of the mineral, points above and below being respectively too high and too low.

discrepancies. Suppose we imagine lead restored to the mineral in sufficient amount to raise the thorium " age " from 613 to 735 m.y. The " ages " then become :

AcD/RaG	AcD/U	RaG/U	ThD/Th
865	803	784	735

Comparison of this sequence with Text-fig. 2 shows that the pattern is still that corresponding to loss of radon. Moreover, the fractured condition of the mineral makes it inevitable that loss of radon must have occurred. From the " ages " given in Table II it is clear that, if the discrepancies were due to loss of radon alone, the most probable age would be 700 m.y. Obviously, like other monazites (cf. Holmes, 1948*a*, p. 192), this one has been subjected to alterations too complex for satisfactory interpretation. The results can be brought into agreement only by assuming that radon, Pb and U have all been lost in appropriate amounts. All that can be deduced with certainty is that the age lies between the limits of 700 and 865 m.y. This conclusion, though unsatisfactory in itself, is at least consistent with the reliable age estimate of 735 m.y. determined from the uraninite.

V. The Pre-Cambrian Sequence in India

The only other orogenic belt in India that has been approximately dated by analysis of radioactive minerals is the Satpura Belt (Text-fig. 1). The general sequence is

Pegmatites, etc.
Granites and migmatites
Iron Ore Series

Sausar and Gangpur Series

The general strike is E.N.E.–W.S.W., and is commonly known as the "Satpura Strike" (Krishnan, 1943). The name of the belt is taken from the Satpura Range, which, though largely capped by Deccan Traps, has an exposed core of ancient metamorphic rocks, migmatites, granites, and pegmatites, with the foliation roughly following the general direction of the Range. Fermor regards these rocks as a geological extension of the "Archaean" rocks of Chota Nagpur, and Crookshank (1936, pp. 196 and 208) provisionally classifies them with the Sausar Series, apart from an isolated group of banded haematite-quartz rocks, which may possibly be the equivalent of part of the Iron Ore Series.

A summary of the geology of Chota Nagpur and of the minerals found in the pegmatites associated with the Chota Nagpur granite in Bihar is given by Dunn (1942). The pegmatites of the Gaya and adjoining districts constitute the world's leading source of muscovite. Radioactive minerals have been found in certain localities, notably around Singar, 35 miles E.S.E. of Gaya, and at Ranchi, 100 miles S.S.E. of Gaya, and some of these have been analysed (Table IV).

TABLE IV

THE "AGES" OF URANINITE AND MONAZITE FROM MICA-PEGMATITES NEAR SINGAR, GAYA DISTRICT, BIHAR

	Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	*Apparent Age in m.y.*
A.	8·66	67·46	(7·0)	(·116)	(·90)	(830)
B.	8·92	64·30	8·12	·123	·89	885
C.	·49	·23	10·55	·045	·02	960

A. Uraninite. *Analyst*: W. R. Criper, in T. H. Holland, *Mem. Geol. Surv. India*, **34**, 1902, p. 131. Criper did not determine ThO_2, but from his analysis it is clear that this could not have exceeded 8 per cent. Th is therefore taken as 7 per cent. Without Th the "age" is 850 m.y.

B. Uraninite. *Analyst*: A. Holmes, 1918, p. 86. Only Pb and U were determined originally, as it was not then realized that the end product of thorium was also an isotope of lead. To complete the analysis Th was determined on a sample of the same powder in 1932.

C. Monazite. *Analyst*: T. C. Sarker (1941).

The "age" calculated from my analysis of uraninite is almost certainly too low, as the mineral, though free from visible alteration products, was riddled with cracks. Loss of radon would seem to have been inevitable. This uncertainty will shortly be cleared up, as Professor Nier has undertaken the isotopic analysis of lead separated from the

analysed powder. Criper's analysis gives an " age " of the same order, but his material was also of inferior quality and again the loss of radon which is suspected would lead to a low result. Sarkar's monazite " age " is likely to be of the right order, but it is impossible to say whether it is too high or too low (cf. Holmes, 1948*b*, p. 123, for evidence that monazite may give results either way). Meanwhile it may be concluded that the age of the minerals is not far from 900 m.y.[1]

The above evidence is adequate to show that the Satpura Belt represents the geological cycle immediately preceding the Delhi Cycle. Moreover, if the correlation of the ancient rocks of the Satpura Range with the Sausar Series is correct—and the apparent continuity of trend (see Text-fig. 1) strongly supports the views of Fermor and Crookshank—then it follows that the Aravalli System and the orogenic belt to which it belongs are older still. The broad sequence in the Pre-Cambrian areas of India under consideration thus appears to be as follows :—

Vindhyan

735 m.y.
DELHI CYCLE (= Cuddapah ?)

ca. 900 m.y.
SATPURA CYCLE

ARAVALLI CYCLE (= Dharwars ?)

GNEISSIC COMPLEX (= Bundelkhand in part ?)

The Dharwars referred to in the above chronological classification are the N.W.–S.E.-trending rocks of Southern India (e.g. Mysore ; see Rama Rao, 1936). There can be no doubt that these rocks represent a very ancient orogenic belt and possibly more than one. The relative age of the belt can be arrived at by another route. The Dharwar belt is sharply cut across by the Eastern Ghats belt (Krishnan, 1943*a*) which must therefore represent a younger cycle. The Eastern Ghats belt in turn appears to be cut across by the Satpura belt. Krishnan, for example (1943*a*, p. 141), writes : " My observations in parts of Orissa seem to show that the Satpura strike is later than and superimposed on an earlier one, apparently that of the Eastern Ghats." Unfortunately, the evidence from radioactive minerals in the case of the Eastern Ghats belt is at present highly discordant. Minerals suitable for dating purposes occur in the mica-pegmatites of the Nellore

[1] Since the writing of this paper, Dr. Leland and Professor Nier have completed the isotopic analysis of lead from sample B. The results, which will be published in *The American Mineralogist*, show that the age is 955 ± 40 million years.

district, amongst them samarskite. Two analyses of samarskite have been made (Table V). Attention is directed to this extraordinary discrepancy in the hope that the analysts concerned will meet the challenge by repeating and continuing their work.

TABLE V

SAMARSKITES FROM THE MICA-PEGMATITES OF THE NELLORE DISTRICT

	Pb	U	Th	$\frac{Pb}{U+Th}$	$\frac{U}{U+Th}$	*Apparent Age.*
A.	·54	4·07	1·17	·103	·78	830
B.	2·09	7·41	1·74	·228	·81	1550

A. *Analysts* : Sarkar and Sen Sarma (1946).
B. *Analysts* : Karunakaran and Neelakantam (1948).

At the moment, however, it can be concluded either that the Satpura and Eastern Ghats belts are of about the same age or that the Eastern Ghats belt is older than the Satpura belt. The tectonic evidence strongly favours the second view. In either case the Dharwars are older than both. Rocks of the Eastern Ghats and Satpura belts should therefore no longer be referred to as " Dharwars " as they commonly have been in the past (Krishnan, 1935 ; Fermor, 1936, p. 214). To do so would be to perpetuate a mistake that is analogous to the misuse of the term " Laurentian " in North America. The original Laurentian rocks of the Grenville Province have a closing age of just over 1,000 m.y. (Holmes, 1948*a*, pp. 180–4). The post-Keewatin pegmatites of the Rainy Lake area have an age of nearly 2,000 m.y. (Holmes, 1948*a*, pp. 189–193 ; Ahrens, 1949). Yet the post-Keewatin granites and migmatites have also been called " Laurentian ", implying an entirely unjustified correlation with rocks 800 miles away and completely unconnected. Similar mistakes have been made in all the better-known Pre-Cambrian shields and only now, with the progress of mapping and the aid of radioactive minerals, is it becoming possible to disentangle the long succession of orogenic belts which make up the so-called " Archaean ", once thought to represent an era of world-wide orogenesis.

VI. METHODS OF CHEMICAL ANALYSIS (by A. A. Smales)

Uraninite.

The *lead* was determined gravimetrically as sulphate on 5 gm. sample, after filtering off silica rendered insoluble by evaporation of the nitric acid solution. Alcohol was not added to complete the precipitation of the lead sulphate since the filtrate was required for the determination of thorium and uranium. Instead the amount of lead remaining in solution was determined by the following procedure :—10 ml. 0·005 N $CdCl_2$ solution were added to an aliquot of the filtrate equivalent to 1 gm. sample, the acidity adjusted to approximately N/100,

and the lead and cadmium precipitated as sulphides by a stream of H_2S. The combined sulphides were then dissolved in hydrochloric acid, H_2S was boiled off and lead determined polarographically after diluting so that the final HCl concentration was 1N (see Smales, 1948). The cadmium added may also be determined polarographically simultaneously, affording evidence that the H_2S precipitation is complete. The amount of lead recovered in this way was 0·40 mg. (= 0·04 per cent) in each of two duplicates ; the main gravimetric lead figures being 7·92 and 7·90 per cent Pb, giving a total lead of 7·96 and 7·94 per cent ; average 7·95 *per cent Pb.*

Thorium was determined on 2 gm. aliquots of the lead sulphate filtrate by precipitation first as oxalate and then as peroxynitrate. Since the amount of ThO_2 so obtained was lower than was expected, a further determination was carried out on 10 gm. sample. The figures obtained were 1·3, 1·3, and 1·5 per cent Th ; average 1·4 *per cent Th.*

Uranium was determined both gravimetrically and volumetrically on 0·5 gm. aliquots of the lead sulphate filtrate ; gravimetrically as U_3O_8 after allowing for rare earth plus thorium oxides in the precipitate obtained with ammonium hydroxide in the absence of CO_2 ; volumetrically by titration with permanganate after passing through a Jones reductor, trivalent uranium being oxidized by a gentle stream of air before addition of ferric alum solution. Results obtained were 72·9 and 72·7 per cent and 73·0 and 73·1 per cent U respectively ; average 72·9 *per cent U.*

Monazite.

Lead was determined both by the gravimetric method of Schoeller and Powell (1940) on 10 gm. sample, care being taken to keep the acidity for the lead sulphide precipitation as low as possible ; and by the polarographic method (on 1 gm. sample) used in a previous analysis of monazite (Smales, 1948) where the amount of sample was limited. Results obtained were 0·535, 0·526 per cent and 0·52, 0·52 per cent respectively ; average 0·525 *per cent Pb.*

Thorium was determined as usual on a 1 gm. sample via oxalate and peroxynitrate, the latter precipitation being carried out three times to ensure separation from cerium. Results obtained were 16·4, 16·5 per cent ; average 16·45 *per cent Th.*

Uranium was determined polarographically on a 1 gm. sample by the method used previously (Smales, 1948), directly after removal of lead as sulphate, since it was shown that separation of thorium and rare earths, and of any titanium present was unnecessary, providing the latter was present in the quadrivalent state. Results obtained were 0·68 and 0·68 per cent ; average 0·68 *per cent U.*

VII. Lead Isotope Analyses (by W. T. Leland and A. O. Nier)

As in earlier work (Nier, 1939 ; Nier, Thompson, and Murphey, 1941), the isotopic analyses were made with a mass spectrometer. Basically, the present instrument is similar to those used earlier. PbI_2 vapour is ionized by electron impact, the ion beam after suitable acceleration is sent through a magnetic field to accomplish a mass separation and the ion currents are measured electrically. There are, however, a number of major differences in the present apparatus : (1) Instead of filling an entire section of the spectrometer tube with lead iodide vapour a small furnace installed in the ion source acts as a source of vapour (Nier, 1938). (2) The mass spectrometer employs a 60° magnetic field and is very similar to another we already described (Nier, 1947). The stronger magnet described at the end of that article is employed. (3) Readings are taken with a recording potentiometer rather than manually. Readings were taken in both the Pb^+ and PbI^+ positions of the spectrum. Because of the improved efficiency of the present apparatus, analyses have been made on as little as 3 mg. of PbI_2. A more complete description of the new apparatus and its applications will appear elsewhere.

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Hilt's Law and the Volatile Contents of Coal Seams

By O. T. Jones

Abstract

Dr. Trotter's recent theory of devolatilization of coal seams is criticized on structural grounds and the " square law " suggested is shown to be no improvement on many other expressions of varied types. The data are best represented both for South Wales and the Kent Coalfield by Hilt's law. The influence of depth of burial on coal vegetation is discussed ; loss of volatile matter is probably promoted by temperatures, but is almost certainly retarded by high pressures. The Hilt rate is controlled by the chemical-physical factors and may be influenced also by varying rates of sedimentation during the accumulation of the Coal Measures.

THE change in the volatile content of coal seams with depth in a vertical sequence which has been observed in coalfields has been variously attributed to (1) the presence of a body of magma below the coalfield, (2) the effect of tectonic forces, and (3) the depth to which the seams were formerly buried beneath the surface. The question has attracted fresh notice recently as the result of a paper by Dr. F. M. Trotter, 1949, on the Coal Seams in South Wales.

That author explains the loss of volatiles with depth as due to " pressure by tectonic forces ", and maintains that the view which attributes the process to magmatic heat has few adherents to-day except to explain local effects due to the intrusion of dykes or sills into or in close proximity to a coal seam.

Dr. Trotter's theory is based upon the supposed existence of a plane of Main Thrust which is identified at the surface with the well-known Careg Cennen disturbance but which, unlike that disturbance everywhere else along its outcrop, is supposed to be a great thrust from the south which passes with a very low inclination under the coalfield. The formula in which the theory is embodied involves the inclination of this plane at any point ; it can be written :—

$$\sqrt{V_2} = \sqrt{V_1} - \frac{\cos\theta}{K} Y$$

where V_2 and V_1 are the volatiles of two seams in a vertical sequence at a depth Y apart ; K is a constant and θ is the inclination of the plane. Since there are fifty-seven seams represented in various sequences in the coalfield (see pp. 409–412) there are many pairs of volatiles which when plotted against the depth between them would give $\frac{\cos\theta}{K}$. The general result is that there is no evidence in the figures that θ departs significantly from zero. Dr. Trotter believes that he has obtained the dip from the isovols, and that for a large portion of the

western coalfield it is not more than 5° ; cos 5° differs from 1 by only $3\frac{1}{2}$ parts in 1,000. Thus the isovols which are plotted on a horizontal plane are viewed as if projected on a plane dipping at about 5°. The Main Thrust is supposed to control the volatile content of seams, some of them at a distance of two miles. One must presume that the author believes that the shearing movement on its surface caused a great rise of temperature along the plane ; it would, therefore, be analogous to inserting a hot plate beneath the coalfield—whether the plate be horizontal or sloping at 5° is immaterial. The square law is the last effect that one would expect to follow from the theory of heat conduction ; it seemed, therefore, possible that this law or $V \propto y^2$ might be an illusion and so, indeed, it proved to be. I applied various other types of curves to the available data, viz. the following :—

$V^2 \propto y$ (an inverse parabola), $\frac{1}{V} \propto y$ (a rectangular hyperbola), $V \propto y$ (a straight line, or Hilt's law), $\log V \propto y$ (exponential), and $\log R \propto y$, where R is the percentage ratio of volatile to fixed carbon, or $R = \frac{100V}{100-V}$; in each case V is the volatile content and y the depth below a given datum. Wellman, 1948, claimed that this last expression gave satisfactory results for the Kent Coalfield. In determining the constant K, Dr. Trotter selected three out of the nine sequences which were available ; he then assumed that the volatile contents of the seams at the top and the bottom of each of the three sequences accurately conformed to the square law (omitting any reference to cos θ) and disregarding all the other seams in each sequence, found his constant from these two seams alone combined with the vertical distance between them. The correct method is to determine the constant for each sequence by a least squares solution, taking account of all the data for each sequence. Even so, however, there are such wide differences between the values of the constant for the various sequences that obviously no single value can be applied to the coalfield as a whole (see below). The fact must therefore be faced that *this mathematical law which involves a fixed constant cannot possibly be applied to the South Wales Coalfield*, and for this reason Dr. Trotter's theory must be rejected, or at best regarded as a poor approximation.

The values obtained by least squares for each sequence from east to west are as follows :—Blaenavon (2188), New Bridge* (2066), Bargoed (1742), Blaengarw* (1774), Penrhiwceiber (1582), Treherbert (1445), Resolven* (2056), Dulais Valley (2593), and Gwendraeth Valley (4630), those selected by Dr. Trotter being indicated by a star. The value corresponding to these which was adopted by Dr. Trotter is 2050 or $1450 \times \sqrt{2}$. The mean of the figures for the three sequences

selected by Dr. Trotter is 1965, but this is the geometric mean, the arithmetic or true mean being 1957 as compared with 2050 adopted. The average for all the above sequences, which are of variable depth ranges, was obtained by giving weights to each value proportional to the depth range of that sequence ; the true mean of all the above is thus 1970 $\pm$ 630, but if we exclude the value for the Gwendraeth Valley the true mean is 1910 $\pm$ 230.

The result of trying to force a particular value (2050) of the constant on to every sequence is seen in the poor correspondences between calculated and observed values shown on pp. 409–412. The sum of the squares of residuals in these correspondences is very large in comparison with those obtained from any one of the various expressions referred to above, even the worst of them (see table).

COMPARISON OF VARIOUS FORMULAE

	S Vo	S Vc	S·Δ	S Δ²
Dr. Trotter's calculations (pp. 409–412) . The remainder are all least squares solutions.	963·8	952·7	38·8	61·19
Dr. Trotter's Square law . . .	—		33·2	36·86
Hilt's law	—		32·6	34·58
Inverse parabolic law	—		36·1	37·40
Rectangular hyperbolic law . . .	—		37·4	58·21
Exponential law	—		33·7	40·19
Wellman's law	—		32·0	36·96

In this table S stands for the sum of and Δ for the residual or difference between observed and calculated volatile percentages.

It will be seen that judged by the sums of the residuals and the sums of their squares, the results derived from the application of the above expressions to the South Wales sequences fall into the following order of merit : Hilt's law, Wellman's exponential ratio law, Trotter's square law correctly applied, the inverse parabolic law (which runs it close), the exponential law, the rectangular hyperbola, followed last of all by Dr. Trotter's own calculations.

The sums of the calculated volatiles on a least squares solution must agree closely with the sums of the observed volatiles in any given sequence and are not therefore given in the Table but according to Dr. Trotter's own calculations they do not agree.

It may appear strange that given data representing the relations between volatiles and depths can conform in varying degrees of approximation to such very diverse laws as $V \propto y^2$ and $V^2 \propto y$. The reason is that the volatiles/depth curve is so nearly straight for ranges

of depth of the order of 2,000 feet that any curve, if its origin is at some distance away, becomes virtually a straight line within that range. Added to this there is a considerable " scatter " of the residuals which seems to be inherent in coal seams so far as is at present known and is several times the probable error of the analytical determinations.

The result of the somewhat laborious calculations embodied in the above Table is to show that Hilt's law is sufficient for all practical purposes and no advantage is gained by using any other law.

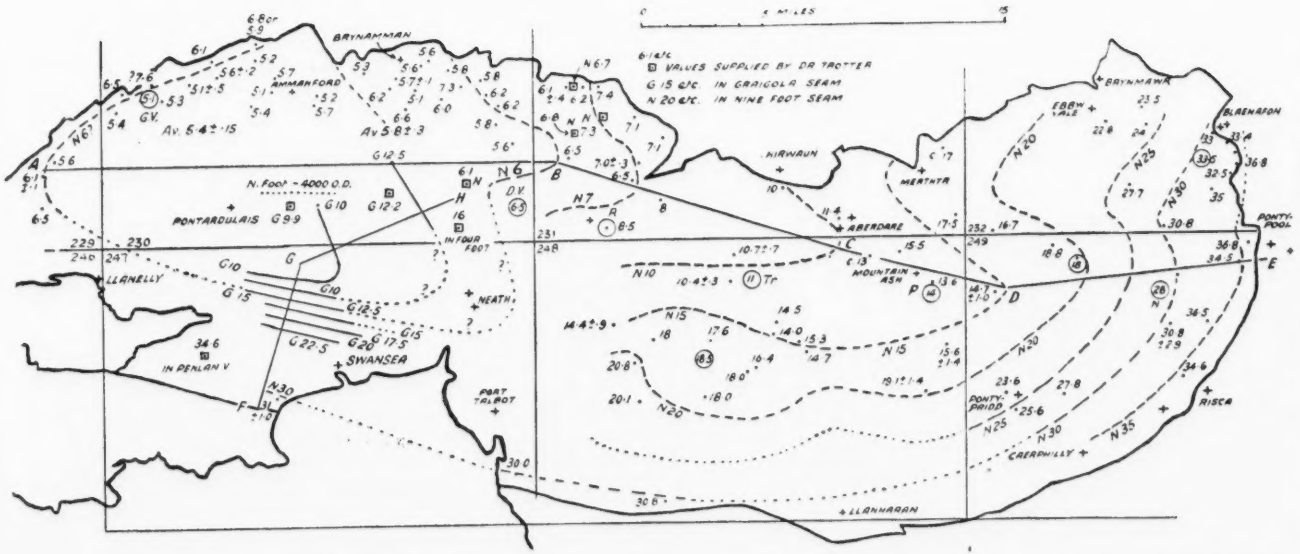
Besides examining the validity of Hilt's law a further object of this paper is to see how far the remaining theory that devolatilization is a consequence of the former burial of coal seams to a depth of many thousands of feet below the surface can account for the loss of volatiles in coal seams. Three sets of data are examined which are derived from (*a*) the South Wales Coalfield, (*b*) the Kent Coalfield, and (*c*) the Pie Rough borehole, North Staffordshire.

(*a*) The South Wales Coalfield

The Geological Survey published a large number of chemical analyses (Pollard and Strahan, 1908) of various seams from this coalfield. Many of these analyses were made in the Geological Survey laboratory, and both proximate and ultimate analyses are given.

In view of the large variations in volatile percentages within the coalfield, minor errors which may occur in comparison with modern analyses are relatively of little importance. From the recorded proximate analyses I constructed for the eastern and north-western parts of the coalfield a map showing the distribution of the volatile contents of the Nine-Foot seam which has been approximately correlated from one end of the coalfield to the other ; again, in view of the scale of the phenomenon, minor errors of correlation have little effect upon the picture. The distribution of volatiles is indicated by lines of equal volatile percentages or isovols, but the actual percentages are also recorded on the map. Where values were obtained by transferring from other seams just above or below, their means and probable errors are given (Text-fig. 1).

Since 1930 the Fuel Research Coal Survey which, until it was transferred to the National Coal Board in 1947, was under the Department of Scientific and Industrial Research, have carried out a large number of new analyses which have not yet been published. On the basis of the proximate analyses which were made the officers of the Coal Survey, 1944, published (*a*) an isovol map, and (*b*) an explanatory pamphlet. This map (reproduced in Trotter, fig. 8) was also based in the main upon the Nine-Foot seam and what were believed to be its correlatives in various parts of the field. The isovol map based on the



TEXT-FIG. 1.—Isovol map of the S. Wales coalfield based on the Strahan-Pollard coal analyses. The south-west portion based on the Coal Survey isovol map (1944).

Strahan-Pollard analyses and that constructed from the more recent analyses differ only in minor details and it would be difficult in most areas to prove that there is any difference between them. For the region north-west of Swansea, however, the Strahan-Pollard analyses are not sufficient to do more than indicate the general trends of the isovols in the seams which are there worked. These seams lie in or just above the base of the Pennant Sandstones and thus some thousands of feet above the horizon of the Nine-Foot seam. The Coal Survey map gives a much better representation of the isovols of the principal seams and I have adopted them, but referred them all to one seam, the Graigola (G). The significant features of these maps are (1) the parallelism between the isovols N_{30} or N_{35} and the present margin of the field from Blaenavon on the east to Gower in the west ; (2) by contrast the trend of the isovols across the northern margin indicating that a large area of the former Coalfield has been removed by erosion ; (3) the two isovol minima, one running in the length of the field, and the other ranging N.W.–S.E. north-west of Swansea. These reflect the former geological history of the field.

The Ministry of Fuel and Power, 1946, published a list of nine vertical sequences of coal seams with their volatile percentages and the depth of each, by reference to some datum. These were also got together by the South Wales Coal Survey. These sequences are given in Dr. Trotter's paper (pp. 409–412) and, together with the isovol maps, must form the basis of any investigation made at the present time into the relation between volatile percentages and existing or former depth of burial in the South Wales Coalfield.

Hilt's Law

It has long been maintained that there is a decrease in the volatile content or an increase in the carbon content of coal seams with increasing depth at any part of a coalfield ; this is usually stated as Hilt's law. The validity of this law has not been adequately tested hitherto, but the nine vertical sequences mentioned above afford a good opportunity for doing so. A linear relation between volatile percentage and depth in a given sequence is assumed, so that if Vo is the probable percentage of volatiles in the top seam of a sequence and V that in a lower seam at a depth y below the horizon of Vo,

$$V = Vo - hy$$

where h is a constant which is called herein the Hilt rate. It is convenient to represent this rate as the change per cent of volatiles per 1,000 feet of depth. The constants Vo and h have been determined by the method of least squares. The results are contained in the following Table.

Sequence and Page	Range of Depth in Feet	h	Sum of Residuals		Sum of Squares of Residuals
			+	−	
Blaenavon and Varteg (p. 409)	785	5·31	2·1	2·1	4·90
*New Bridge and Crumlin (p. 410)	1,905	5·32	3·6	3·6	11·58
Bargoed (p. 410)	2,365	5·53	2·8	2·7	5·35
*Blaengarw (p. 410)	2,055	5·20	3·3	3·3	7·86
Penrhiwceiber (p. 411)	2,378	5·50	1·3	1·2	2·35
Treherbert (p. 411)	1,648	5·26	1·3	1·4	1·35
*Resolven (p. 412)	2,457	3·31	·8	·7	·67
Dulais (p. 412)[1]	2,082	2·18	·6	·6	·24
Gwendraeth Valley (p. 412)	805	·97	·5	·7	·28
			16·3	16·3	34·58

Those marked with a * were used by Dr. Trotter to determine the constants in his formula.

The first six sequences are in the eastern half of the coalfield and their mean, weighted according to the range of depth over which each holds, is 5·37 ± ·11 which is an average rate of change of 1 per cent in a depth of 186 feet. The uniformity of the rate is noteworthy, especially when it is compared with the marked and progressive decrease which sets in farther west between Treherbert and Resolven. These three western sequences correspond to a rate of change of 1 per cent in 302 feet, 459 feet, and 1,031 feet respectively. These figures illustrate very clearly the difficulties that anyone must encounter in attempting to apply Hilt's or any other law with a uniform constant to the coalfield as a whole. There is no doubt, however, that, within the limits of variation which at present appears to be inherent in different coal seams, Hilt's law holds for this coalfield not only in a qualitative sense but quantitatively. Before dealing with the significance of these varying rates in the South Wales Coalfield, it is interesting to see how they compare with those in the Kent Coalfield.

(*b*) The Kent Coalfield

The stratigraphy of this coalfield was described by H. G. Dines, 1933. The coal measures are about 2,800 feet thick and are overlain unconformably by Mesozoic rocks, the base of which lies roughly between 800 feet and 1,400 feet below Ordnance Datum (see Dines, fig. 1). Some mine shafts and numerous boreholes enable the depth to the base of the Coal Measures to be ascertained as illustrated by a contoured map (Dines, fig. 2). In the main the Coal Measures

[1] The lowest seam at 2082 is omitted by Dr. Trotter.

rest with a non-sequence on Carboniferous Limestone but towards the north-west they transgress on to older rocks. The deepest part of the basin is at Waldershare (3,850 feet below O.D.), and its axis there ranges east-south-east towards Maydensole ; westward the course of the axis becomes indefinite. Folding of the basin " in the main post-dated the deposition of the coal-bearing strata, although there is evidence that it was in progress during their deposition ".

The lowest 700 feet consists of shales with coal seams but towards the north-western part of the field sandstones appear among these shales. The upper part consists mainly of sandstones with coal seams ; near their base the Millyard seam is widely developed and at their top the Beresford seam is found over a small area beneath the Mesozoic cover. " There is a slight diminution in the thickness of the strata between the Beresford and the Millyard seams outwards from the centre of the basin suggesting that folding was in progress during deposition."

Apart from some disturbances in the seams which in many respects resemble washouts, the rocks are little disturbed and with minor exceptions the beds dip gently at angles not exceeding 4°. There do not appear to be any large faults though some faults with small downthrows have been found in all the workings. The tectonic effects in this coalfield are therefore trivial in comparison with those in the South Wales Coalfield.

The volatile contents of the seams vary between 35 per cent and 10·5 per cent, and cover, therefore, exactly the same range as the six eastern sequences of South Wales. The lowest seams just fail to reach the anthracite rank of 9·5 per cent.

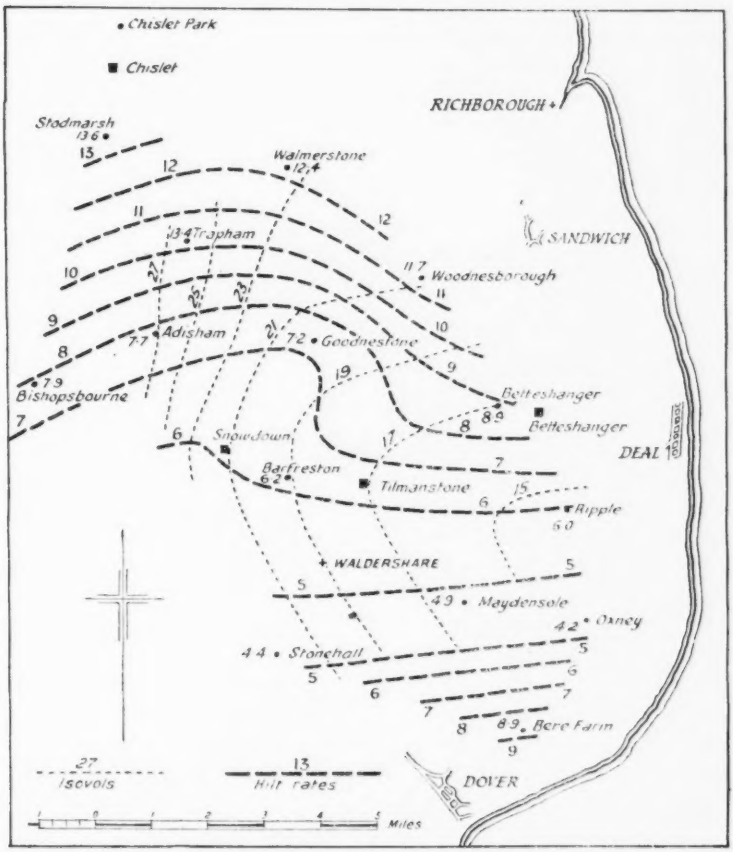
As the isovols in the Beresford and Millyard seams show (Dines, figs. 4 and 5), the volatile percentages decrease from west to east and thus in the opposite direction from South Wales. The lowest volatiles do not coincide with the deepest part of the basin, and their horizontal variation cannot be accounted for by the present conditions in the field. Dines remarks, " it is possible that the present distribution of the volatiles was determined by a cover of strata overlying the Coal Measures which was removed before the present cover was laid down."

The volatiles decrease generally in a vertical direction but there are some exceptions where the depth interval is not large. On the whole, however, it is obvious that in a qualitative sense Hilt's law holds.

There are fourteen vertical sequences based on boreholes and one based on colliery workings, for which volatile percentages of the seams are known ; these furnish a good opportunity of testing Hilt's law for this Coalfield. The constants were determined for all sequences

by least squares. As for South Wales many other expressions were also tried for comparison but none of them show any advantage over Hilt's law.

The Hilt rates for each sequence are shown in Text-fig. 2. There is a



TEXT-FIG. 2.—Distribution of Hilt rates and isovols of Millyard Seam, Kent Coalfield.

remarkable decrease in the rates from north to south, the rate at Oxney being less than one-third of the rate at Stodmarsh and it is evident from their distribution that the variation of Hilt rates is systematic. The figures for Trapham are somewhat erratic and may include some errors. This place does not fall into line with surrounding places. There is, unfortunately, only one sequence, Bere Farm, in the south ; the rate there appears to indicate an increase to the south even more rapid than anywhere farther north. These lines of equal

rates appear to define sharply an axis ranging nearly through Oxney and Stonehall along which the Hilt rate hardly exceeds 4 per cent per 1,000 feet. On the same map some of the isovols of the Millyard seam, taken from Dines' map (Text-fig. 5) are shown.

It is obvious that there is no direct relation between the trends of the Hilt rates and those of the isovols ; in fact, the two trends are nearly at right angles. This, together with the fact that the minimum axis of the volatiles does not coincide with the deepest part of the basin, have proved serious stumbling blocks in attempting to account for the variation of Hilt rates in this coalfield, and no satisfactory explanation has been offered.

(*To be concluded.*)

New Species of Calymenidae from Scotland and Ireland

By ARCHIE LAMONT

(Grant Institute of Geology, University of Edinburgh)

(PLATE XVIII)

ABSTRACT

Four new species of Calymenidae distinctive of horizons of stratigraphical interest are described. Observations of two pairs of anterior pits in the axial furrows of *Platycalymene éire* sp. nov. and *P. duplicata* (Murchison), not corresponding with the first lateral furrows of the glabella, indicate a trisegmental origin of the frontal lobe. A possible correspondence of the trilobite hypostome with chelicerae of Arachnids is propounded.

Family CALYMENIDAE Milne Edwards, 1840

Genus PLATYCALYMENE Shirley, 1936

Platycalymene éire sp. nov.

Pl. XVIII, figs. 1–2

Diagnosis.—Glabella low, narrowing in front, parabolic. Median part of occipital ring arched up and longer than lateral parts which are narrow and point slightly forwards. Third (basal) glabellar lobes pointed in front but not projecting beyond outline of glabella. Third glabellar furrows oblique, deep, continued backwards in a groove which turns nearly parallel to axis of glabella, only becoming shallow just before it meets the occipital furrow. Anterior outline of frontal lobe well rounded ; the lobe rises steeply but not high above preglabellar field ; no overhang ; greatest width immediately behind small anterior pits. Preglabellar field only gently uptilted ; anterior half with moderate roll-like thickening.

Anterior margin of cranidium convex forwards and gently convex over axis. Cheeks extend further forward than glabella, descend steeply to axial furrows or even overhang a little. Axial furrows wider opposite frontal lobe and second glabellar lobes, but narrowing somewhat where raised eyelines run forward and inward to reach floor of furrows opposite rear of frontal lobe. Slight convexity in a lateral direction of floor of axial furrow between small pit at end of eyeline and faint anterior pit opposite narrowing part of frontal lobe. Palpebral lobes roughly opposite rear half of first glabellar lobes. In this position fixed cheek is about half width of glabella. Cheek rises steeply from posterior marginal furrow which meets axial furrow at an angle of about 75°. Posterior border of cheek is narrow and runs obliquely forward.

Surface ornament, thorax, and pygidium unknown.

Dimensions.—Length of cranidium, 10·7 mm. ; length of glabella, 7·5 mm. ; width of glabella across basal lobes, 7·0 mm.

Holotype.—Lamont Collection No. 36.

Horizon.—Lower, less muddy facies of Stage 3 of the Tramore Limestone ; not far under beds with *Nemagraptus gracilis.*

Locality.—Roadside, Newtown Glen, 1½ miles south-south-west of Tramore, County Waterford.

Remarks.—Platycalymene éire occurs on the same small slab with *Trinucleus hibernicus* Reed, *Remopleurides salteri* Reed, and fragments belonging to *Tramoria punctata* Reed.

The most instructive comparison seems to be with *Platycalymene duplicata* (Murchison) *forma mas* Salter, which is illustrated in Pl. XVIII fig. 4. In it the proportions of glabellar length to breadth across basal lobes correspond with those of *P. éire*, but in the latter the anterior part of the glabella is much narrower. In both forms of *P. duplicata* the anterior roll is more pronounced, the cheeks much wider, and the extended eyeline ends in the axial furrow close to a pit—possibly antennary—just behind the anterior pit (Pl. XVIII, figs. 3–4).

These pairs of anterior pits, of which the front pair may be somewhat elongate laterally, point to a trisegmental origin of the frontal lobe. The front pair may indicate points of attachment of appendages which have fused to give the hypostome. This hypothesis is supported by the existence of clawlike projections on the posterior margin of young Calymenid hypostomes. There may even be homology with the chelicerae of Arachnids, e.g. *Hughmilleria* (Clarke and Ruedemann, 1912, pl. 59, fig. 2). The rostrum in Calymenidae may correspond with the epistome in *Hughmilleria* (compare Stubblefield, 1936, fig. 2*c*, or Henriksen, 1926, fig. 8, with Størmer, 1944, fig. 9, no. 6).

The lateral parts of the occipital ring in *Platycalymene duplicata* do not point forward ; and, except towards the lateral extremities, this also applies to the course of the posterior marginal furrow. *P. éire* shares with *P. duplicata forma femina* the tendency for the front part of the axial furrows to be wider. The glabellar furrows are more oblique in *P. éire*, but this and anterior pointing of basal glabellar lobes are more marked in internal moulds. In *P. duplicata* the pre-ocular branches of the facial sutures converge forwards throughout most of their length, but in *P. éire*, much as in *Reacalymene pusulosa* Shirley, it is only the front parts which converge. *R. pusulosa* has different sizes of granules on the raised anterior border, quite like *P. duplicata*, but the pre-glabellar field is narrower than in *P. éire* and is bounded in front by a more angular ridge. The glabella in *R. pusulosa* extends in front of the raised anterior parts of the fixed cheeks.

The glabellar outline of *Platycalymene éire* and the reduction of the first glabellar lobes point towards a trend like that seen in *Flexicalymene caractaci* (Salter), but *P. éire* has no intermediate lobation between the basal and second glabellar lobes and is also distinguished

by its very oblique glabellar furrows. The lateral glabellar lobes of *F. caractaci* are more inflated, but in *P. éire* we probably see the ancestral condition. *F. aldonensis* (Reed) shows less oblique lateral glabellar furrows and more inflated lobes, along with sharply upturned narrow anterior border and great backward migration of the eyes. *P. tasgarensis* Shirley has the frontal lobe of the glabella and the cheeks narrower than in *P. duplicata*, but not so narrow as in *P. éire*.

Genus FLEXICALYMENE Shirley, 1936

Flexicalymene scotica sp. nov.

Pl. XVIII, figs. 6–7

Diagnosis.—Glabella broad, wider than long, rising above cheeks, and strongly and evenly inflated from back to front and from side to side. Basal glabellar lobes rounded, inflated, each one-third of basal width of glabella. Third lateral glabellar furrows transverse but continued obliquely backwards behind intermediate lobes. Large rounded second lateral lobes bounded by oblique furrows in front and separated from axis of glabella by shallow wide longitudinal grooves. First lateral lobes very small, rounded, failing by their own diameter to reach general outline of glabella as indicated by outer margin of second lateral lobes. Furrows separating first lateral lobes from frontal lobe very short. Frontal lobe oblong, more than three times wider than long, has straight front margin with slight re-entrant angle on axis, and rises steeply with some overhang above concave preglabellar field. Anterior border is turned up at right angles to a line joining preglabellar field to occipital ring. Occipital ring bends upward and forward over axis, is not lobate but laterally is about a third as long as the basal glabellar lobe in front of it.

Axial furrows are convex outwards, wide, with slight constriction opposite second and third lateral glabellar furrows and occipital furrow ; widest beside small first lateral lobes. Cheeks inflated, but lower than glabella, extend as far forward as front of glabella and overhang the lateral prolongation of the preglabellar field. Palpebral lobes rise high in line with front part of second glabellar lobes and small first lobes. Anterior branches of facial sutures converge slightly in front, but the anterior border measured from side to side is very broad. It rises evenly over median line and is somewhat convex forwards. Posterior branch of facial suture diverges sharply outwards almost at right angles to the anterior branch.

Dimensions.—Length of cranidium, 12·0 mm. (approx.) ; length of glabella, 8·5 mm. ; width of glabella across basal lobes, 10·5 mm.

Holotype.—Lamont Collection, No. 32.

Horizon.—High Mains Sandstone (? Hirnantian).

Locality.—Small grassy knoll, 100 yards west of High Mains farmhouse, north-west of Dailly, South Ayrshire.

Remarks.—It will be seen that this species has affinities with *Flexicalymene meeki* (Foerste) of the Cincinnatian and with *F.* cf. *meeki* (Lamont) (1935, Pl. VIII, figs. 10–11 ; Shirley, 1936, Pl. XXIX, fig. 8) from the Lower Drummuck Group, but *F. scotica* differs in the much shorter first lateral glabellar lobes and in the emarginate flattened outline of the anterior part of the broad frontal lobe. *F. quadrata* (W. B. R. King) is distinguished by greater inflation of the anterior part of the glabella as seen in profile (Shirley, 1936, p. 391, fig. 2) and by almost equal-sized first and second glabellar lobes.

Though possessing no buttress, *Flexicalymene scotica* has much the same inconspicuous first lateral lobes as *Calymene planicurvata* Shirley from the Upper Llandovery. In neither of these species do the glabellar lobes " stand out from the general outline " as Shirley puts it. In *C. planicurvata*, however, the frontal lobe is longer and rounded anteriorly and the anterior part of the glabella rises higher above the preglabellar field than in *F. scotica*, in which maximum convexity of the profile is seen at a position between the second lateral lobes.

Flexicalymene is mainly an Ordovician genus, but it has been recorded in the Silurian, as for example by E. D. Gill (1945, p. 182). Taken in conjunction, however, with a form of *Hirnantia sagittifera* (McCoy) that occurs in the High Mains Sandstone, it may indicate a high Ordovician horizon such as Hirnantian (cf. Lamont, 1935).

Genus Calymene Brongniart, 1822

Calymene hadyardensis sp. nov.

Pl. XVIII, figs. 8–12

Diagnosis.—Cephalon sub-triangular, rounded in front. Preglabellar field narrow, very slightly concave, nearly parallel to plane of rest of dorsal shield. Anterior border not thickened, except opposite anterior ends of axial furrows, where a row of about three small tubercles may be carried. Glabella bell-shaped, almost as long as broad. Occipital ring longest over axis, where it is massive, strongly arched forward and upward, with sharp pustule on anterior border and two widely spaced pustules on each side, narrow laterally with incipient elongate lobe pointing obliquely forward. Basal glabellar lobes projecting, well rounded, inflated, connected by short necks sunk below general level to axial part of glabella. Third lateral furrows transverse, deep, turning back, and then with short shallow transverse continuation, so outlining low indistinct intermediate lobes. Second lobes hemispherical, not projecting as far as basal lobes, separated from rest of glabella by longitudinal furrow. First pair of lobes, very short and transverse,

extend laterally beyond outline of frontal lobe which is short, semi-oval, and overhangs strongly in front, with a width little more than half that of the anterior border between facial sutures. Anterior parts of fixed cheeks project beyond first lateral furrows of glabella and overhang carrying two large pustules in front and one behind close to the axial furrow and near where the eyeline, itself carrying two more pustules, begins to run obliquely backwards to the small palpebral lobe. Another pustule appears near the summit of the buttress. The longer axis of the palpebral lobe diverges outwards in front so interrupting the course of the facial suture which behind it swings gently outwards and then runs in a straight line towards the genal angle. The form of the posterior branch of the suture is like that of a question-mark. A group of two or three pustules occur on the free cheek close to the anterior end of the posterior branch of the facial suture. Just in front of the eye the free cheek is folded down sharply at an angle of 90° or more and a few widely spaced pustules may appear along the line of folding. There is a deep rounded lateral marginal furrow, outside which the lateral border, angulate towards the genal extremity, carries a few pustules as we trace it forward, and finally developes a bevel, with sparse tubercles on the inside of the later, before it reaches the anterior branch of the facial suture. The bevel slopes forward and beneath it a strong, shelly shield is formed on the underside of the cephalon which laterally attains a length nearly equal to half that of the fixed cheek behind the eye. Buttress pustulate, rounded rather than angular, comes very close to second lateral glabellar lobes ; axial furrow deep and convex outwards against basal lobes. Very wide posterior marginal furrow. Posterior border flattened distally and covering antero-lateral half of first thoracic pleura.

Thorax of thirteen segments tapers gently in a posterior direction. Axis is one-third of width. Inner and lateral parts of pleurae are roughly equal except in front where the inner parts are relatively longer. Outer parts are flat and nearly at right angles to the convex inner parts. Axial rings show articulating half rings. Lateral parts of first three rings narrow, pointing forwards, slightly lobate with occasional small pustules. Lateral extremities of axial rings 4, 5, and 6 are more flattened and carry pustules which increase in size as we follow them backwards. Posteriorly the extremities of the axial rings are narrower again, but the pustules become short spiny processes pointing obliquely upwards and outwards, diminishing on rings 12 and 13. The posterior bands of pleurae are twice as long and more convex than the anterior bands. Outside the fulcrum the posterior bands become still longer and flattened, except for a posterior ridge which sweeps forward in a gentle curve providing a raised margin for the flattened anterior part which merges with the anterior band. On

some of the posterior thoracic segments, however, a fine incised line continues to separate the distal parts of the anterior and posterior bands.

Pygidium is roughly triangular, with six axial rings, rapidly decreasing in breadth, distally curving forward round shallow appendifer pits to terminate pointing obliquely forward in slight swellings, one or two of which carry tiny pustules, above broad axial furrows. A post-axial swelling is separated by a marked transverse furrow from the rest of the rachis. Five pleurae seem to be present with occasional pustules. At decreasing distances from the axis, as we go in a posterior direction, the first four pairs of pleurae are flexed backwards and bent downwards and inwards towards the underside. Fifth pair of pleurae short, nearly parallel to axis.

Dimensions.—Length of cephalon, 6·5 mm. ; width of cephalon, 15·0 mm. ; length of glabella, 5·5 mm. ; width of glabella across basal lobes, 6·0 mm. ; length of thorax, 14·0 mm. ; length of pygidium, 4·0 mm. ; width of pygidium, 7·0 mm.

Holotype.—Grant Institute of Geology Collection.

Paratype.—Lamont Collection, No. 33.

Horizons.—Bargany Pond Burn Group (Lower Gala) and Penkill Group (Lower Gala).

Localities.—North side of Hadyard Hill, south-west of Dailly (holotype) ; Penwhapple gorge, near Penkill Castle (paratype).

Remarks.—Small spines on lateral parts of axial rings towards posterior end of thorax may have served to discourage attack while the front part of *Calymene hadyardensis* was submerged in mud. From the figure in Pl. XVIII, fig. 11, the tendency for arching up of the posterior part of the thorax will be seen. The sharp downward bend of the pygidium recalls the condition in a specimen attributed to *Calymene subdiademata* McCoy (1851, pp. 166–7, Pl. 1F, fig. 10*a*) from Coniston Waterhead. The specimen which should be treated as type was figured from Leintwardine (fig. 9 and 9*a*), but appears to have been lost. Shirley suggests (1933, p. 65) that *C. subdiademata* is a *nomen nudum*, but the present writer can hardly agree as it seems to apply to a species resembling *C. hadyardensis* but differing in a more thickened and upturned anterior border.

The maximum convexity in a longitudinal profile of the glabella of *Calymene hadyardensis* is on a line joining the first lateral glabellar lobes (Pl. XVIII, fig. 11), but this has been over-emphasized by slight damage to the specimen, due to some projecting hard body inside—possibly the hypostome.

The projecting basal lobes of the glabella remind one of the condition in *Calymene camerata* Hall from the Coralline Limestone, at Schoharie,

New York State. A similar condition is also seen in *C. carlops* sp. nov., more especially in young specimens (Pl. XVIII, fig. 18).

The nearly flat preglabellar field and border in *Calymene hadyardensis* comes as a surprise in a characteristically Silurian form. It probably indicates adaptation to shallow burrowing probably in search of food or when eggs were being laid.

As well as the pustules on the cheeks a few appear to have been distributed on the frontal and basal lobes of the glabella, but the state of preservation renders them unclear, though part of the original exoskeleton where preserved seems to have had a coppery-red hue.

Calymene carlops sp. nov.

Pl. XVIII, figs. 13–19

Diagnosis.—Cephalon triangular, rounded in front ; strongly convex from front to back ; convexity from side to side forming an arc of a circle over the glabella but with somewhat flattened lateral parts of cheeks projecting beyond this. Glabella bell-shaped, longer than wide, with basal lobes protruding up to about half their diameter beyond second lateral lobes. Maximum curvature of longitudinal profile at or just in front of first lateral lobes. Front half of frontal lobe with semi-oval outline, slightly emarginate, overhangs most on either side, less on axis where a longitudinal rise crosses the preglabellar field. Sparse larger pustules among smaller ones, sometimes connected by fine raised lines, are seen especially on the front part of the glabella and on its lateral lobes, also on the pointed anterior parts of the fixed cheeks and on the upturned anterior border. Sides of the frontal lobe are parallel and high above axial furrow carry traces of small additional lobes (" fourth lobes " of Shirley) in front of the vertically elongate, slightly projecting first lateral lobes. Anterior pits in axial furrows against parallel sides of frontal lobe ; smaller pits nearly opposite first lateral lobes. Larger, more protuberant second lateral lobes, separated from median part of glabella by shallow semi-circular depressions, overhang the axial furrows as much as do the sharply cuspate buttresses opposite them. Basal lobes prominent, connected to glabella by depressed " necks ". They carry four or five fairly large ill-defined pustules. Occipital ring convex, massive, very long over axis, rounded ; narrower and slightly flexed forward at sides. Posterior part of axial furrow overhung by the basal glabellar lobes but not by steeply rising posterior part of fixed cheeks. Palpebral lobes opposite front part of second lateral lobes. Facial suture behind palpebral lobes curves in a little before turning outwards at right angles to glabella. Anterior branch of facial suture at first parallel to glabella, then concave towards it, before it meets swollen lateral extremity of sharply upturned anterior border which is bent back so as to overhang the

deeply excavated lateral areas of the preglabellar field. Just inside the suture a longitudinal rise connects the anterior border with the steep anterior parts of the fixed cheeks. On each of these a short ridge runs obliquely backwards towards the posterior part of the palpebral lobe which is continued backwards in a narrow elevation behind the palpebral lobe.

Thorax unknown.

Pygidium with prominent, tapering axis, occupying fully one-third of width in front, with five or six rings and narrow posterior axial ridge separated off by shallow transverse furrow that is rounded but not so deep as the axial furrow which deepens and becomes wider anteriorly. Four oval appendifer pits on either side occur between the first five rings of the rachis, followed posteriorly by very weak indications of pits. Median tubercles on first two rings of axis. Four pairs of pleurae are bent down and quickly turn backwards outside the axial furrows. Pleurae may be furrowed for about half their length from the posterior margin which they meet at right angles, or they may be simple and much narrower than the segmental grooves. One or two pustules, widely spaced, may appear on pleurae. Fifth pair of pleurae short, practically parallel to axis. Rear margin, as viewed from behind, is bent up almost forming a right angle. In dorsal view, from above, it is decidedly emarginate behind the short post-axial ridge which carries a single dorsal pustule.

Dimensions.—

	Lamont Colln. *No.* 34.	*R. Scott. Mus. Colln.* *A.*	*B.*
	mm.	*mm.*	*mm.*
Length of cephalon . .	7·5	5·5	
Width of cephalon . . .	14·0	10·0	
Length of glabella . . .	6·7	4·5	3·3
Width of glabella . . .	5·5	4·0	2·7
	No. 35.		
Axial length of pygidium .	3·5		
Width of pygidium . .	5·0		

Syntypes.—Lamont Collection, Nos. 34 and 35.

Horizon.—Plectodonta aff. *canastonensis* siltstones, Pentlandian (Upper Gala).

Locality.—Deerhope, north of Carlops, Pentland Hills.

Remarks.—In North America the Niagaran *Calymene celebra* Raymond is related to *C. carlops.* It has the same type of pygidium which may have been derived by a simplification of a form like that in *Platycalymene* (Pl. XVIII, fig. 5). *C. carlops* has the frontal lobe of the glabella broader and the anterior border is wider and curves back to a greater degree laterally. In the last respect there is resemblance to *C. antigonishensis* McLearn, which, however, has the anterior border

swollen more as in *C. intermedia* Lindström from the Wenlock and (*fide* Shirley, 1933, p. 64) Aymestry Limestone and Kirkby Moor Flags. McLearn (1924, p. 163) reports his species from the McAdam (?), Moydart, and Stonehouse formations of Nova Scotia. He spreads out these formations from Woolhope to "Upper Ludlow", but the McAdam may correlate with the Pentlandian and the Moydart and Stonehouse not be as late as he believes.

Calymene laevis Lindström has longer bell-shaped glabella and narrower frontal lobe, but as in *C. carlops* small "fourth" lobes appear (1885, Pl. XVI, fig. 5). Closest akin to *C. carlops*, however, seems to be *C. frontosa* Lindström, which comes from the oldest beds of the Marlshales, near Wisby, and which differs mainly in having a more tapering and shorter frontal lobe of the glabella which is also more strongly papillate than the Pentland specimens. A similar difference in ornament holds between *Cyphoproetus* (*Carlopsia*) *glaudii* Lamont from the Pentland Hills and the strongly pustulate *Cy. punctillosus* (Lindström) from Gotland. H. Munthe (1910, pp. 1399–1400) places the Marlshales just above the Stricklandia Marl of the Wisby district, which he treats as Upper Llandovery. He correlates the Marlshales with the Wenlock Shale, but they may be somewhat older and seem to have a good deal in common with the Pentlandian, including brachiopods like *Stropheodonta walmstedti* (Lindström) which occurs along with *C. carlops* in the lower part of the *Plectodonta* aff. *canastonensis* beds at the Deerhope and high up on the south side of Wetherlaw Linn.

Calymene blumenbachii Brongniart has the axial furrows less wide and less deeply excavated under the overhanging glabellar lobes and anterior parts of the fixed cheeks. It has the glabella wider in front and coming closer to the anterior border, while the glabellar surface is more abundantly, more finely, and more uniformly papillate. In the pygidium the ribs show more uniform development of pleural furrows and diverge laterally for some distance before they gradually turn backwards. *C. lata* Shirley (Wenlock-Lower Ludlow) has maximum inflation of the glabellar profile further forward than in *C. carlops*, also more uniform and abundant fine pustules, and less sudden retroflexion of the ribs on the lateral lobes of the pygidium. Such differences may be used as evidence of the pre-Wenlock age of the fauna which includes *C. carlops*. It may be added that in the Blair and Straiton beds at Knockgairdner, in S. Ayrshire, the *Calymene* present is not *C. blumenbachii* as stated by Peach and Horne (1899, p. 550) but in all probability *C. carlops*.

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EXPLANATION OF PLATE

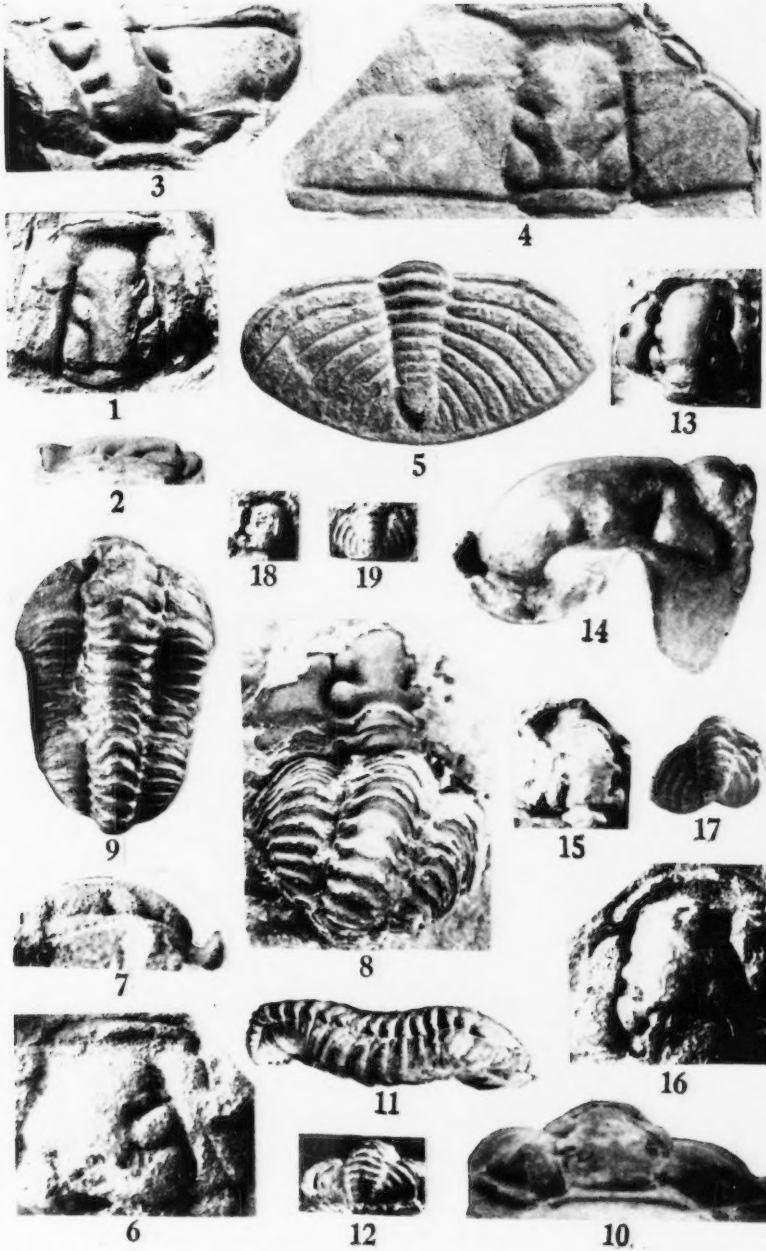
FIG. 1.—*Platycalymene éire* sp. nov. Internal mould of cranidium. Tramore Limestone Stage 3, Newtown Glen. × 2 (Lamont Colln. No. 36).

FIG. 2.—Ditto. Longitudinal profile. × 2.

FIG. 3.—*Platycalymene duplicata* (Murchison) *forma femina* (Salter). Cranidium showing two pits in each axial furrow at proximal ends of eyelines, these pits not corresponding with the first lateral furrows of the glabella. *Forma femina* is broader across the basal glabellar lobes than Salter's *forma mas*. Quarry south-west of Llan Fawr, Llandrindod Wells. × 2 (Chamberlain Colln., 144/32, Birmingham University).

FIG. 4.—*Platycalymene duplicata* (Murchison) *forma mas* (Salter). Internal mould of cranidium with two pairs of anterior pits. Glabella relatively narrow as measured across basal lobes. Llan Fawr Quarry (*Nemagraptus gracilis* beds). × 2 (Lamont Colln., No. 37).

FIG. 5.—*Platycalymene duplicata* (Murchison). Internal mould of pygidium. Same locality and horizon. × 2 (Lamont Colln., No. 38).



New Species of Calymenidae from Scotland and Ireland.

FIG. 6.—*Flexicalymene scotica* sp. nov. Internal mould of cranidium. High Mains Sandstone, 100 yards west of High Mains farmhouse, Dailly. × 2 (Lamont Colln., No. 32).

FIG. 7.—Ditto. Longitudinal profile. × 2.

FIG. 8.—*Calymene hadyardensis* sp. nov. Partly decorticated cephalon and thorax. Posterior thoracic segments have short spines at lateral ends of axial rings. Impure limestone, Penwhapple Gorge, Penkill. × 2 (Lamont Colln., No. 33).

FIG. 9.—*Calymene hadyardensis* sp. nov. Internal mould of complete dorsal shield. North side of Hadyard Hill, south-west of Dailly. × 2 (Grant Institute of Geology Colln.).

FIG. 10.—Ditto. Anterior view. × 3.

FIG. 11.—Ditto. Profile. × 2.

FIG. 12.—Ditto. Pygidium. × 2.

FIG. 13.—*Calymene carlops* sp. nov. Internal mould of cranidium. *Plectodonta* aff. *canastonensis* siltstones, Deerhope, Pentland Hills. × 2 (Lamont Colln., No. 34).

FIG. 14.—Ditto. Longitudinal profile. × 6.

FIG. 15.—*Calymene carlops* sp. nov. Internal mould of small cranidium. Same horizon, high on south-west side of Wetherlaw Linn. × 3 (Grant Institute of Geology Colln.).

FIG. 16.—*Calymene carlops* sp. nov. Internal mould of cranidium. Same horizon, Deerhope. × 3 (John Henderson Colln., 1876, 42/6*A*, R. Scottish Museum).

FIG. 17.—*Calymene carlops* sp. nov. Internal mould of pygidium. Same horizon and locality. × 2 (Lamont Colln., No. 35).

FIG. 18.—*Calymene carlops* sp. nov. Internal mould of small cranidium. Same horizon and locality. × 2 (John Henderson Colln., 1876, 42/6*B*, R. Scottish Museum).

FIG. 19.—*Calymene carlops* sp. nov. Internal mould of small pygidium. Same horizon and locality. × 2 (John Henderson Colln., 1876, 42/6*C*, R. Scottish Museum).

CORRESPONDENCE

MAGMA TYPES

SIR,—The recent paper by Mr. M. K. Wells and Dr. A. K. Wells on Magma Types (*Geol. Mag.*, 1948, p. 349), and the letter thereon by Professor A. Holmes (*Geol. Mag.*, 1949, p. 71), have caused me to consult my own use of the term. This occurs in my paper " On the Basaltic Lavas penetrated by the Deep Boring for Coal at Bhusawal, Bombay Presidency ", *Rec. Geol. Surv. Ind.*, liii, p. 196 (1925). This paper was written in Calcutta during the recess period of 1924, so that my use of the term " magma-type " was made in ignorance of its use by the authors of the Mull memoir published in the same year, to which, consequently, I make no reference.

As a result I find that I have used the term with a significance somewhat different from that of the Mull memoir. My paper contains a record, with description of the mineralogy and petrology, of 1,171 feet vertical of horizontal basaltic lavas of the Deccan Trap formation pierced in a deep bore-hole for coal. The study of the cores showed that twenty-nine flows had been cut, and that the range of thickness of the twenty-seven flows completely pierced was from 5 feet to 97 ft. 3 in., with an average thickness of 40 feet. No analyses were made of these rocks, but from the microscope study, making use of mineralogical and other peculiarities, it was possible to arrange them into seven groups based on the absence or presence of phenocrysts of olivine and labradorite, and on whether these had remained suspended in the flow or had sunk towards the base. These seven groups were made into two types according to peculiarities exhibited by the iron-ores ; and it was these two more comprehensive groups that were designated magma-types, on the hypothesis that they had come from different magma-sources.

Sub-crustal and intercrustal magma-basins are discussed on the assumption that these basaltic rocks had come as liquids from subterranean sources, often carrying in suspension phenocrysts of labradorite and olivine of intratelluric origin. The evidence was held to show that the difference between the porphyritic basalts with phenocrysts of labradorite and olivine and non-porphyritic basalts was entirely due to gravitative settling within a magma-reservoir, and I did not find any evidence for the hypothesis that the olivinic and non-olivinic basalts came from different ultimate sources. My two magma-types each include porphyritic and non-porphyritic basalts. It may be that chemical analysis would show that these two types have no wide-reaching special significance. I do not see why they should, as I attribute all these Deccan Trap effusions to the same ultimate source, namely my infra-plutonic eclogite shell.

Professor Holmes may already know the answer to the question whether there is any significant difference chemically between my two magma-types, since many years ago he asked for, and was I believe supplied with, specimens of my Bhusawal basalts for purposes of chemical study.

Yours faithfully,

L. L. FERMOR.

24 DURDHAM PARK,
BRISTOL, 6.
2nd July, 1949.

EAST ANGLIAN DRIFTS

SIR,—It is distinctly hard on Mr. Baden-Powell that the evidence which led to my East Anglian views should have been produced, and illustrated, in London so soon after his letter was written. For that reason it would be unfair to take his attitude as final, and futile to start a discussion until that evidence, notably as to Corton and Hoxne, is published and can be assessed.

In the meantime may I make a general comment, addressed not so much

to Mr. Baden-Powell, as to all those who oppose this Undermelt Theory and the conclusions arising therefrom. Since the gage has been thrown, their task is to defend the orthodox view that here in Northern England we had a series of ice advances and retreats, the latter marked by extra-glacial sedimentations which may or may not be of Interglacial rank, but do at any rate indicate periods of deglaciation. What they have to show, therefore, is that all the peculiarities of the laminated clays, silts, and sands within the drifts of that area can be matched in unquestioned lacustrine, estuarine, or marine deposits which are preferably, though not necessarily, built up from the erosion of Glacial detritus : *all* is the operative word, please. But that is not the end, for they then have to account for the till-on-sand contacts and " roof-falls ", as I call them, harmonizing them with forward ice-movements. If they would wait until the new evidence of which I have spoken is published, they would then have all the data before them, and could go ahead secure in the knowledge that no further mines are to be sprung in their path.

In this matter, I do not take my stand on being partly right, but on being wholly right. There was in Britain but one great glaciation—the Saale, or Mindel of the Alps : the rest were but small mountain affairs. Rarely in geology has there been an issue so clear-cut as this. In truth, there is no room here for that compromise so dear to the British mind, or even for that which is so dear to the professional mind, the making of a simple thing complicated. And the curious-minded will find a commentary on the situation as a whole on page 198 of W. B. Wright's *Quaternary Ice-Age ;* the first edition, not the second. Subject apart, what he had to say serves to admiration our present business.

R. G. CARRUTHERS.

HIGH BARN,
STOCKSFIELD ON TYNE.
20th July, 1949.

REVIEWS

GEOLOGY OF THE NORTHERN PENNINE OREFIELD. Volume I. Tyne to Stainmore. By K. C. DUNHAM. Memoir Geological Survey of Great Britain, pp. 357, with 33 text-figures and 4 folding plates. 1948. Price 17*s.* 6*d.*

This admirable volume is based on a war-time reinvestigation of the mineral deposits of the Northern Pennines by an author pre-eminently fitted for the task. It deals mainly with the area of Carboniferous rocks extending southwards from the Tyne valley to the Stainmore gap, between Barnard Castle and Brough, a region once famous for its lead mining and still an active producer of barytes, witherite, and fluorspar.

A brief outline of the history of mining is followed by a lucid account of the stratigraphical succession, with its remarkable repetitions of rhythmic series, or cyclothems, in the Middle Limestone Group of the Carboniferous Limestone Series, and by a short description of the igneous intrusions, notably the Whin Sill and related dykes. The gentle asymmetric dome structure of the Alston Block is well illustrated by a map which not only shows contours on the base of the Great Limestone, but also displays the perfect conjugate pattern of the vein-fissures throughout the orefield. These fissures, associated with normal faulting, typically steepen and widen out in the harder beds, and since the tearing-apart of their walls is probably due to tension resulting from domal uplift, it unfortunately follows that the width of openings propitious for ore deposition must diminish as the veins are followed in depth—an inference borne out by past mining operations. Owing to their physical response to fracturing, the hard limestones, dolerite,

and sandstones are particularly congenial as hosts to vein oreshoots, and within the limestones and Whin Sill these shoots may be widened by replacement of the wall-rocks. The other type of ore deposits, the metasomatic flats, are formed by the replacement of flat-lying favourable limestones and are always accompanied by feeding channels. Frequently the flats appear to have developed where the formation of vein oreshoots was inhibited, and elsewhere they are localized along gentle anticlines.

Descriptions of the primary minerals, notably lead and zinc sulphides, fluorite, barite, and various carbonates, are followed in turn by valuable accounts of their zonal distribution, the nature of wall-rock alteration in different kinds of country rock, and the effects of secondary, oxidation processes. Then, in a statement on the nature of the mineralizing solutions and the origin of the deposits, the author concludes that a hydrothermal derivation most adequately explains the primary mineralization of the Northern Pennines, a conclusion that few are likely to dispute. No decisive evidence is yet offered to settle the vexed question as to the exact age of the hypogene mineralization. After citing arguments in favour of Permo-Carboniferous (Hercynian) and Tertiary ages, it is suggested that in view of the widespread fluorite-barite replacements of the Lower Magnesian Limestone a post-Lower Permian age seems probable, and that cogent reasons may still be forthcoming to clinch the case for a Tertiary date.

More than 200 pages are " devoted to descriptions, by areas, of the details of mineral deposits, summarizing the wealth of information which has been collected during the re-examination of the orefield ". This splendid achievement will for long remain the outstanding reference on the subject, and a much-valued boon to all concerned with the future mineral development of this area, wherein several virgin tracts, particularly in the Great Limestone, are deemed worthy of exploration in the hope of finding new orebodies.

The general excellence of this Memoir will certainly enhance the Geological Survey's reputation for work on economic mineral deposits.

D. W.

A Study of the Structure, Classification, and Relationships of the Palaeozoic Arachnida. Based on the Collections of the British Museum. By A. Petrunkevitch. Transactions of the Connecticut Academy of Sciences, vol. 37, 1949, pp. 69–315, i–xi, pls. 1–83. New Haven, Conn. Price $7.70.

Some years ago, Ray Lankester separated the Eurypterida and the Xiphosura from the Crustacea, and considered them as orders of the class Arachnida. The author of this excellently illustrated and scholarly memoir is a well-known zoologist who, for some forty years, has specialized among Arachnida, including their fossil representatives. To him, Arachnida form a class of an equal taxonomic grade to Eurypterida and Xiphosura ; the three classes together form part of the Chelicerata, sharing the presence in their members of only six pairs of cephalo-thoracic appendages of which the first pair lie in front of the mouth. The Arachnida differ essentially from the other groups in the absence of compound eyes, and in the possession of lung-books or tracheal tubes instead of book-gills. Professor Petrunkevitch, in a new classification, interprets the class as comprising four sub-classes on the basis of the junction between the cephalothorax and the abdomen, the backward displacement of the mouth, and the position of the proximal joints of the chelicerae. Two of these sub-classes disappeared before the close of the Palaeozoic era. Sixteen orders are now recognized within the four sub-classes, their characters are discussed, keys to families and genera are provided, and evolutionary trends are indicated for some of the structural features, particularly those to be seen in fossils. Here, the author's skill in cleaning the material and in photography become evident ; indeed, his comments on the latter subject are most valuable. He stresses the dangers in interpreting dorsal and ventral abdominal surfaces when these have been

superimposed during fossilization ; he demonstrates instances where, by removing matrix bearing the mould of the inner surface of the dorsal wall, he has exposed the ventral wall ; this technique has led to new discoveries, and caused him to revise not only T. I. Pocock's earlier classification, but the modified version of this which he used himself as recently as 1945.

The present memoir arises from the author's study at Yale of Palaeozoic Arachnida lent to him in 1946 by the authorities of the British Museum (Natural History). In conformity with the regulations of that museum, figured specimens were not lent though some described but unfigured material was made available. The major part of the collection studied came from clay-ironstone nodules found some ten feet above the Thick Coal at Coseley and Dudley in the South Staffordshire Coalfield. These fossils were collected by Messrs. W. Egginton, W. Hind, W. Madeley, H. Johnston, S. Priest, and others. The author's reinforcement and revision of Pocock's work means that now some thirty Arachnid species are known from these beds, and these are classed into twenty-four genera distributed among nine of the twelve orders known to occur in Palaeozoic times. From an approximately similar horizon at Crowcrook in the Durham Coalfield, seven species are described, of which six are congeneric and two conspecific with the S. Staffordshire fauna. Knowledge of the two successively earlier Coal Measure faunas (the supposed Pennystone of Coalbrookdale and the Arley Mine of Sparth Bottoms, Lancashire) has not been materially increased except to change Pocock's generic reference of two species from *Anthroscorpio* to *Eoscorpius*. A small number of Lower Carboniferous specimens were studied, but though they are discussed, none of S. Hirst's genera from the Devonian Rhynie Chert were examined, neither were the two known Scottish specimens of Silurian scorpions. It is good to learn, however, that this year the author is visiting Europe for the purpose of studying the type material of Palaeozoic and other fossil Arachnida, and the publication of further results of this high calibre are awaited with interest.

C. J. S.

THE GEOLOGY OF THE BRITISH EMPIRE. By F. R. C. REED. pp. viii + 764, with 26 folding maps and figures. London : Edward Arnold. 1949. Price 70*s*.

The first edition of this book was published in 1921 : the present, the second edition, was just completed by the author before his death, and was finally passed through the press by Sir Edwin Pascoe, who has also died since its appearance. He disclaims having made any serious alterations in the MS. It is curious to look back upon the changes that the imperial idea has undergone in the last twenty-eight years. In 1921 everybody took the Indian Empire for granted, as one of the brightest jewels of the British Crown. Now it is in a most peculiar condition, an independent republic with some kind of a link within the Commonwealth : Burma is now completely independent : Ceylon a self-governing dominion, and so on. However, the author has perhaps wisely ignored all this and simply revised the existing text, even including Palestine, which is certainly not part of the Commonwealth.

The material originated as lecture notes at Cambridge delivered to advanced students, and it is to be feared that the material in the end ran away with the lecturer. There is always the tendency to add another reference to the bibliography, which in some cases grew to be enormous, e.g. India and Burma, 479 items, Australia, 346, Canada and Newfoundland, 676. These are far too much detail, and a good idea is spoiled by excess. However, some of the shorter chapters on small islands are excellent.

Since most of the components of Gondwanaland were originally included in the book it is of interest to speculate whether the author believed in continental drift. He never seems to speak positively on the subject, but one cannot help feeling that he was a believer, from geological evidence, although he could not bring forward a positive proof. This is the most sensible attitude to take.

R. H. R.

PETROLOGY OF THE NORTHAMPTON SAND IRONSTONE FORMATION. By J. H. TAYLOR. pp. vi + 111, with 7 plates, some coloured, and 10 text-figures. *Mem. Geol. Survey*, 1949. Price 12*s.* 6*d.*

The Northampton Sand ironfield has at present the largest output of any in Britain, having of late years surpassed the Cleveland field, which fifty years ago was an easy first. Now the Northampton field yields more than half of the British production. It has been worked from Stowe and Blisworth in the south of Northamptonshire to the city of Lincoln, a distance of about eighty miles, and in places it is about twenty miles wide. But by no means all stone is workable. The best type is described as the main oolitic ironstone group : the predominant feature of this group is the presence of carbonate in the groundmass. This is generally siderite, less commonly calcite. When fresh and unweathered these rocks are bright green, but are commonly weathered brown or yellow anywhere near the surface, and " boxstone " weathering is very common. Altogether five types of ironstone are recognized, but other types are not generally worked.

There is now no doubt whatever that the iron of the rock is an original constituent : the idea of replacement, either as supposed by Sorby for Cleveland, or as postulated by Cayeux for Lorraine, is now completely abandoned. It is probable that it is now held only by Déverin, a Swiss disciple of Cayeux, who recently described on these lines some ferruginous oolites in the " Dogger " (Middle Jurassic) of Switzerland.

It is now generally believed that iron oolites are of marine and shallow water origin, the sources of the iron being various, possibly from the Lias or Trias in the case of Jurassic ores, most of which are very much alike, in a broad sense, i.e. they all include a great variety of types, which are repeated over and over again, in different occurrences.

This memoir is illustrated by some very successful coloured plates which show the point just noted : in fact, these plates would do just as well to illustrate the ores of the Yorkshire Dogger, which are just about of the same age (Yeovilian to Aalenian), whereas the Northampton ores are probably all Middle Jurassic. A notable and newly described feature in both is what are now called " spastoliths ", i.e. distorted ooliths, showing that these existed for some time in a gelatinous form.

A large part of this memoir is occupied by the study of the exact composition of the different ores from the point of view of beneficiation, i.e. improvement for purposes of ore-dressing and smelting. Another volume on the stratigraphy of the ironstone will appear later.

R. H. R.

THE GEOLOGY OF LINCOLNSHIRE. By Professor H. H. SWINNERTON and Dr. P. E. KENT. Lincolnshire Natural History Brochure No. 1. 1949. 126 pp., 22 figs., 1 plate, 1 folding plate. Published by the Lincolnshire Naturalists' Union, and obtainable from the Hon. Secretary, Linc. Nat. Union, City and County Museum, Lincoln. Price 5*s.* 6*d.*, post free.

Part of this useful account of the geology of Lincolnshire is written for beginners ; but the authors have incorporated in it summaries of their recent work. For instance, among other topics, Professor Swinnerton deals with the lower Cretaceous, and Dr. Kent with the Lincolnshire Limestone and with the underground structure of the area. A few of the important fossils are figured ; the variation in facies and lithology of the Jurassic and Cretaceous are well illustrated by diagrammatic sections.

A. G. B.

LES GRAPTOLITHES ET QUELQUES NOUVEAUX GROUPES D'ANIMAUX DU TREMADOC DE LA POLOGNE. By ROMAN KOZLOWSKI. *Palaeontologia Polonica* (Warsaw), iii, pp. xii + 232, with 66 text figures and 42 plates. 4to. No price. (The title page bears the date 1948, but a printed slip attached states that distribution commenced July, 1949.)

Professor Kozlowski's monograph on the Tremadocian graptolite fauna of Wysoczki has been eagerly awaited since the publication of his " Informations préliminaires " in 1938 (*Ann. Soc. Zool. Polonici*, xiii). How the completed manuscript, partly in proof, survived the destruction of Warsaw and the German occupation makes fascinating reading ; the plates were prepared in Sweden from negatives stored in Paris throughout the war ; and Professor Kozlowski is indeed to be congratulated on the successful conclusion to his long labours. The illustrations, particularly the 42 quarto plates of the author's drawings, are magnificent ; and the text, scholarly and well-documented, is palaeozoology at its best. Professor Kozlowski has here done for the graptolites what Professor Stensiö did in 1928 for the Ostracoderms ; and it is not too much to say that with the appearance of this work, the study of the graptolites enters on an entirely new phase. For indeed the work has a value out of all proportion to the magnitude and probably local character of the fauna : all the forms described are new and may possibly never be recognized outside Poland, but the conclusions that have been elicited from their study are of a fundamental importance, and will furnish the means of interpreting other and less remarkably preserved material elsewhere.

The material has been derived from three of forty-six thin chert bands occurring in some sixteen metres of fine-grained glauconitic sandstone exposed in the quarry at Wysoczki about 120 miles south of Warsaw. The chert, filling ripple-mark troughs and irregularities in the underlying sandstone surfaces, is clearly syngenetic. The fauna, in which calcareous organisms are conspicuously absent, includes two horny brachiopods indicating an age equivalent to the *Ceratopyge* Limestone of Sweden, some fifty species of graptolites (all new) and representatives of several new groups of doubtful affinity. It is an attached, benthonic fauna, contrasting strongly with previously described Tremadocian graptolites ; but to what the organisms were attached is by no means clear. What will amaze most readers, familiar by repute with the results obtained, is the extraordinarily fragmental nature of the material, most fragments being only two or three millimetres in length.

Professor Kozlowski has already given (1938) a brief summary of the essential branch structure of the Dendroidea with its stolon system and regular triad budding on the " Wiman rule " into stolothecae, autothecae and bithecae, together with some account of the histology of the periderm, comprising fusellar and cortical layers. He has also (*Biol. Reviews*, 1947) provided an excellent summary of his views on graptolite affinities. The corresponding sections of the monograph, therefore, on morphology and affinities, while giving much-appreciated detail (including the first real account of dendroid ontogeny even exceeding in detail what has been done for the Graptoloidea) have necessarily lost something of their novelty. What the reader will probably turn to most eagerly will be the sections dealing with the morphology of the new Orders and of *Eocephalodiscus*, and Kozlowski's brilliant analysis of the organization of the graptolites and the probable nature of the graptolite animal itself. Since it may well be some time before the monograph is generally available, an abstract of these sections may not be unwelcome.

The most general cause of dimorphism in animals is sexual, and although colonial organisms are commonly hermaphrodite, male and female zooids are known both in *Rhabdopleura* and *Cephalodiscus*, the males in *C. sibogae* being reduced and with almost atrophied brachial apparatus. Kozlowski interprets the bithecae as representing such males, the reduced arms being reflected in the universal absence of apertural processes in bithecae. The autothecae housed the females and in several genera have furnished traces of

embryos. The disappearance of bithecae in Graptoloidea represents a transition to hermaphroditism, corresponding to a better adaptation to colonial life, autothecal females becoming hermaphrodite and bithecal males being eliminated. It is possible that in some early graptoloids with small bithecae, the autothecal individuals were already hermaphrodite and the bithecal zooids non-functional; and in certain Camaroidea lacking bithecae there occur what appear to be vestiges of bithecal stolons.

The stolothecae probably did not house separate " stolozooids ", but were secreted by the autozooids at an early stage of development, each autotheca being secreted by the same individual as the stolotheca which preceded it. The general resemblance between bithecae and stolothecae is thus explained on the view that the stolotheca was secreted by an immature individual (autozooid) with pre-oral lobe and tentacles still relatively undeveloped, the bithecae being secreted by male zooids in which these organs never were fully developed. Thus the dendroid colony was composed of two types of individual, autozooid and bizooid, and in typical graptoloids the rhabdosome results from the activity of autozooids alone, related to an unchitinized stolon.

In *Cephalodiscus*, secondary tissue on the outside of the zooidal tubes derives from the mobility of the zooids, which can leave their tubes and creep over the surface of the coenecium. But the laminated cortical layer which occurs almost universally among graptolites as a secondary thickening can only be due to the existence of soft tissue covering the entire colony, for the zooids are attached at the base of the thecal tubes by their stolons. Such an external membrane is known in certain Polyzoa, where it constitutes a direct prolongation of the wall of the upper edge of each zooid. Its presence in the graptolites would indicate a more advanced colonial organization than living Pterobranchs; the zooids, attached at one end by their stolons and by an extra-thecal membrane at the other, could have had but a limited range of movement. A ventral mouth, U-shaped gut, and dorsal anus may be postulated, together with brachial apparatus in the form of tentacles (at least in the autozooids) probably grouped around two arms or in two tufts on account of the pronounced bilaterality of the thecae, especially their apertural modifications.

Minute vesicular bodies present in certain autothecal cavities (particularly occluded thecae) in some camaroid and tuboid species are interpreted as eggs and packets of embryos, and it is further surmised that the quantity and arrangement of these bodies may imply the division of embryos originally far less numerous, i.e. the peculiar embryonic fission known in certain cyclostomatous Polyzoa. The prosicula corresponds to the larva developed from the egg, with little trace of disc or nema; it would be covered with extra-thecal tissue, later secreting disc, nema, longitudinal strengthening ribs (known only in the Graptoloidea) and probably the spiral line. The absence of disc or nema is no proof of a free-swimming larva, since it may have been attached by soft tissue and such genera as *Phyllograptus* in which no nema has been observed were possibly attached throughout life by a stalk of soft tissue.

So distinct is the metasicula from the prosicula that it must either represent a radical metamorphosis or result from an entirely distinct individual; and Kozlowski favours the view that the prosicular individual was replaced by a metasicular individual, following the degeneration of the former. Again, an analogous process is observable in the astogeny of certain Polyzoa.

Synrhabdosomes in the Graptoloidera are interpreted as a development of colonies by budding or the formation of blastozooids; if this view be correct, the siculae of such rhabdosomes, called pseudosiculae by Kozlowski, should have no prosicula portion. The apex of the pseudosiculae (the base of the pseudosicular individual) must have been comparable with the stolonal node of the Dendroidea and perhaps with the rhizoidal budding of such dendroids as *Syrrhipidograptus*.

Turning now to systematics, the graptolitic material falls into four orders, Dendroidea, Tuboidea, Camaroidea and Stolonoidea.

The Order DENDROIDEA is restricted to forms with chitinized stolons and regular budding on the Wiman rule ; their structure is by now more or less familiar, but the wonderfully detailed account of the astogeny of *Dendrograptus* may be specially noted.

Of the remaining orders, the TUBOIDEA have most in common with the Dendroidea though they are sufficiently distinct to warrant ordinal separation. Bithecae and autothecae are present, essentially as in the Dendroidea, but the stolothecae are much less individualized, forming a system of irregular tubes of variable length with stolons equally variable as to size and structure. In place of the regular triad budding of the Dendroidea, budding here is capricious, the spacing of the nodes and frequency of the thecae being alike variable. Two subdivisions are recognized : Tubidendroid and Tuboid. In the former, typified by *Tubidendrum*, the rhabdosome consists of erect ramifying branches united by bithecae or groups of thecae which become incorporated in the adjoining branch, superficially therefore resembling such a dendroid as *Coremagraptus*. Budding instead of producing triad groups, is more usually diad, with any combination except two autothecae ; the basal part of the rhabdosome is unknown. The second (Tuboid) group comprises more irregular, encrusting colonies whose general appearance is familiar in Wiman's *Galeograptus* and *Discograptus*. Here there is a basal encrusting assemblage of thecae termed the thecorhiza, above which project tubular thecae, singly or in clusters. Stolothecae appear to be entirely confined to the thecorhiza ; autothecae are composed of a basal horizontal part associated with the thecorhiza and an erect, free, distal portion ; irregularly distributed bithecae are sometimes limited to the thecorhiza, sometimes projecting above it along with the autothecae. The sicula and ontogeny remain unknown.

The characteristic feature of the CAMAROIDEA is the autotheca, each composed of two parts as in Tuboids, but here more strongly differentiated into an enlarged creeping portion (camara) and an erect tubular portion (collum) ; owing to the irregularity and extreme tenuity of the peristome, it is concluded that there must have been a gradual transition from the chitinous wall to the soft tissue of the zooid. Stolothecae and bithecae are present in some genera, but in others bithecae are absent (sometimes with vestigial stolons) and the stolothecae are indistinct. In one group there appears something comparable with the thecorhiza of the Tuboidea ; in the other the stolons are embedded in extra-camaral tissue (probably representing highly modified stolothecae) above the camarae. Cortical tissue as such is absent. The development of the colony and its adult form are unknown.

Finally, in the STOLONOIDEA, the distinctive feature is the excessive development and extreme irregularity of the stolon, varying from 50–350μ diameter. Fascicles of stolons or single stolons are often included in stolothecal tubes composed of a thin transparent substance with fusellar structure in complete rings (not half-rings as in the other orders). The thecae produced from stolons, apart from stolothecae, seem all to be of one kind and hence presumably autothecae ; they are rarely preserved intact, and the whole group (which seems of minor importance) is known only by exceedingly fragmentary material.

Quite distinct in structure from these graptolite orders are the two specimens of *Eocephalodiscus*. The more complete coenecium was an irregularly ovoid granule about one and one-half millimetres in longer diameter, with irregular crests and dimples and about a dozen small openings distributed over the surface. It was composed of eleven irregularly curved, more or less tubular cells. In the fusellar structure of the test it resembles the graptolites, but differs from them in the irregular development of the cells, their mutual relations, and the absence of stolons. Most of the cells develop insensibly from part of the cavity of previously formed cells, but three are altogether independent of the others. These must have been formed by buds which detached themselves completely as happens in *Cephalodiscus*, and the cortical

layer of the periderm does not imply the presence of extra-thecal tissue but was probably laid down by zooids moving freely over the surface of the colony. Living *Cephalodiscus* exhibit extremes of variation in the form of the coenecium, which the palaeontologist unacquainted with the soft parts might refer to different genera and families, but which are assigned subgeneric rank by the neozoologist. However, the immense time interval separating *Eocephalodiscus* from *Cephalodiscus*, the limited number of cells, and the fact that the soft parts are unknown, is held to justify the erection of a separate family, *Eocephalodiscidae*.

The GRAPTOVERMIDA, GRAPTOBLASTI, and ACANTHASTIDA, comprise minute chitinous skeletons of organisms of a highly problematic nature ; the first two are simple, the last-named colonial.

The method of quoting references in the text by serial number is tiresome, for readers familiar with the literature can usually recognize the identity of a paper cited by author and date, whereas a serial number necessitates constant reference to the bibliography. It is also a pity that no diagnoses are given, and misprints are not infrequent. The latter perhaps, and certainly the regrettably poor quality of the paper used in the text, are explained by the conditions of publication of this classic work.

O. M. B. B.

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